New Scientist

THE YEAR AHEAD

What will the coronavirus do next?
The rise of electric supergrids
mRNA treatments for everything
Large Hadron Collider reboots
Crucial meeting to rescue nature
Quantum computing upgrade
Moon missions galore

WEEKLY 1 January 2022

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Why is laughter funny?

Laughter is an important form of communication, and yet it has long been neglected by scientists. In this talk, University College London's Sophie Scott will reveal what we know about the natural history and neuroscience of laughter, from its role in social bonding to the neural basis of how to perceive other people's chuckling. Join us online on 3 March at 6pm GMT (1pm EST).

True crime

Find out the truth about psychopathy with leading expert Mark Freestone, who helped to create the character Villanelle in smash-hit TV drama *Killing Eve*. Then learn about the latest developments in forensic science with Niamh Nic Daéid at the University of Dundee, UK, who advises crime writers Ian Rankin and Val McDermid. Join us at Conway Hall in London on 16 March from 6:30pm GMT.

newscientist.com/events

Online

Covid-19 daily update

Stay on top of the omicron variant and all the most crucial developments in the pandemic with our briefing, updated every weekday at around 12pm GMT. We round up all the latest news, plus give links to exclusive interviews and features.

newscientist.com/coronavirus-latest

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Peking Man New twists in the infamous case of the missing fossils?

BLACKBOXGUILD/SHUTTERSTOCK

Better together Cuttlefish seem to be more sociable than we thought

Video

Best of 2021

From cuttlefish crowds and the volcano that spews black lava to living robots and Carlo Rovelli's rebellious past, relive our favourite science videos of last year with our carefully curated playlist. Head over to our YouTube channel to tune in.

youtube.com/newscientist

Newsletter

Our Human Story

Get Michael Marshall's monthly newsletter about human evolution delivered for free to your inbox. In the latest edition, he looks at claims of new evidence in the case of the Peking Man fossils, a trove of hominin remains found in China in the 1920s that later disappeared.

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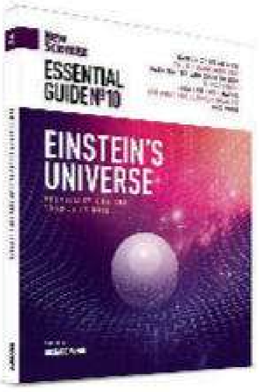
Newsletter

> **"So many decades on, it seems unlikely that Peking Man will be found"**



Essential guide

How did the universe begin? What is it made of? Do black holes exist? Albert Einstein's space- and time-warping theories of relativity have revolutionised our view of the cosmos over the past century. Find out how in the 10th *New Scientist Essential Guide*, available now.

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PALLADIUM
CHALLENGE CONTEST

Nornickel, the world's largest producer of palladium and high-grade nickel and a major producer of platinum and copper, announces the start of the Palladium Challenge, a contest with a USD 350,000 prize fund organised in partnership with the International Precious Metals Institute (IPMI).

The Palladium Challenge is an initiative intended to inspire individuals, businesses and academic institutions to invent and design a sustainable use-case that features and increases the demand for palladium. The metal is known for its catalytic capabilities and unique physical properties, and while it is widely used in the automotive industry as an essential component of catalytic conversion, the Palladium Challenge seeks to broaden its applications and spark innovation.

The Palladium Challenge will be judged by an independent panel of global experts who will review all submissions.

The **top three projects** will receive global recognition and **will be awarded monetary prizes on September 16, 2022** at the IPMI Annual Platinum Dinner in New York City.

THE PRIZES WILL BE AS FOLLOWS:

1st Place:
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Registrations are now open on the IPMI website **https://ipmi. corgano.com**. Completed proposals must be submitted no later than May 31, 2022.

All entries are subject to the Official Rules of the Palladium Challenge.

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The year ahead

From biodiversity to space travel, here are our predictions for 2022

HELLO and welcome to the first issue of 2022 – and our predictions of what the year ahead holds (see page 7). This magazine went to press as the omicron variant of the coronavirus was on the rise. As the pandemic enters its third calendar year, we look at the likely evolution of further variants and the need for yet more boosters in the next 12 months.

Thankfully, news is cheerier elsewhere. The mRNA technology used in the Pfizer/BioNTech and Moderna coronavirus vaccines has gone from experimental to essential in record time, and researchers are investigating whether it can be used to treat everything from cystic fibrosis to heart disease, with human trials potentially beginning in 2022. Sticking with medicine, a row about an Alzheimer's drug approved in the US in 2021 is set to rumble on, as it isn't clear whether the medicine is tackling the right target.

We also have some really big science projects to look forward to. The Large Hadron Collider has spent the pandemic in a coincidental lockdown, but comes out of a three-year upgrade ready to push forward the frontiers of theoretical physics.

> "The COP15 summit in China is a chance for world leaders to align biodiversity and climate goals"

Speaking of frontiers, if all goes to plan, a veritable fleet of spacecraft are headed to the moon, with around a dozen probe launches planned. The European and Russian space agencies are also partnering on a mission to look for life on Mars.

One of the big stories from 2021 (besides the pandemic, of course) was the COP26 climate summit, held in November in Glasgow, UK. This April, there is a sequel of sorts: the COP15 biodiversity summit in Kunming, China, which was originally due to take place in 2020, but has been repeatedly postponed due to, well, you guessed it. Assuming the meeting goes ahead, it is a chance for world leaders to align biodiversity and climate goals, pledging to preserve fragile ecosystems.

Finally, there are the long shots. Progress on both quantum computers and electrical supergrids is expected to gather pace in 2022, with some even talking up the prospect of a quantum device that can actually perform useful tasks. It is unlikely, but then who knows? As the past few years have shown, predicting the future is a mug's game. ▮

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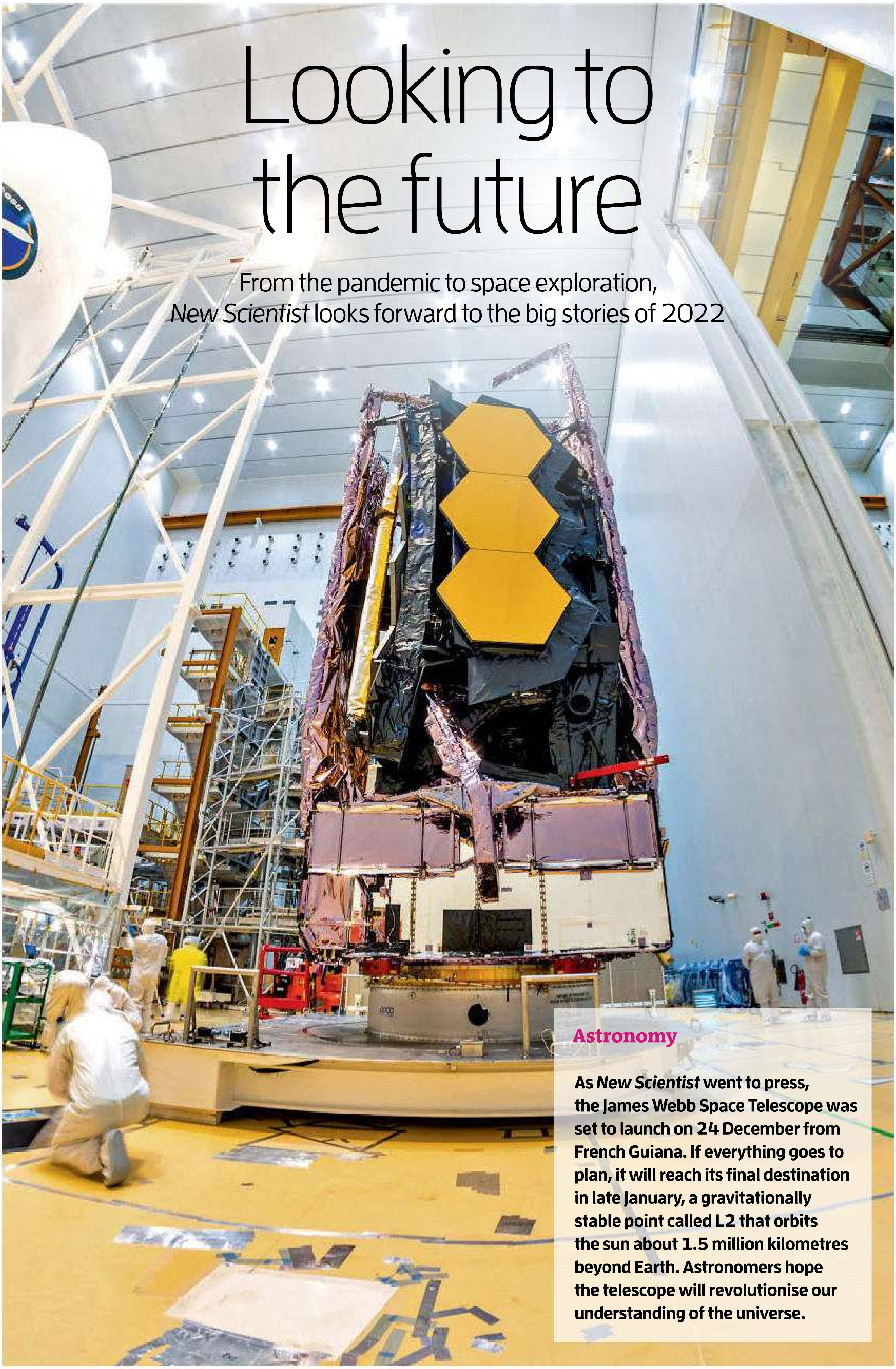
Looking to the future

From the pandemic to space exploration, *New Scientist* looks forward to the big stories of 2022



ESA-M.PEDOUSSAUT

Astronomy

As *New Scientist* went to press, the James Webb Space Telescope was set to launch on 24 December from French Guiana. If everything goes to plan, it will reach its final destination in late January, a gravitationally stable point called L2 that orbits the sun about 1.5 million kilometres beyond Earth. Astronomers hope the telescope will revolutionise our understanding of the universe.

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2 **mRNA marvel** Technology behind coronavirus vaccines will find new uses **p9**

3 **Alzheimer's disease** Row over controversial drug set to continue **p11**

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6 **Quantum computers** Will 2022 be the year they finally become useful? **p15**

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8 **Ready for launch** All the big space missions set to take off in 2022 **p18**

Renewable energy

The rise of supergrids

There is growing momentum to use high-voltage cables to connect power grids around the world, says **Adam Vaughan**

1

INDIA gained notoriety when it finished November's COP26 climate summit by weakening a move to end the use of coal. Less widely recognised is that the country also started the Glasgow summit in a more positive fashion, with a plan to massively expand the reach of solar power by joining up the electricity grids of countries and even entire continents.

Indian prime minister Narendra Modi has talked about the idea before, but the One Sun One World One Grid initiative launched in Glasgow now has the backing of more than 80 countries, including Australia, the UK and the US.

The alliance is just one example of a growing movement to create regional and, eventually, global "supergrids": long-distance, high-voltage cables linking each country's growing renewable power output.

The supergrid movement is being driven partly by the need to maintain a smooth flow of power onto electricity grids. Local weather makes the amount of power generated by wind and solar variable, but this becomes less of an issue if the grid is larger and distributed over a wider geographical area.

What's more, supersized green energy projects are often sited far from the cities or industrial areas demanding their energy, be it wind farms in the North Sea or solar farms in the Australian outback. Supergrids offer a solution to this problem by connecting large renewable energy sources with the people who use the power.

"The Indian government is keen on links to the Middle East, to help India decarbonise using imported renewable energy," says Jim Watson at University College London.

The UK, one of India's partners on the One Sun One World One Grid initiative, is also considering new long-distance cables.

Last September, the UK started importing hydropower from Norway via a 724-kilometre subsea cable. In the coming years, the cable is expected to be used mostly to export electricity from the UK's growing number of offshore wind farms so that it can be stored in hydropower facilities in Norway and released onto grids as needed.

In 2022, UK start-up Xlinks will try to persuade the UK government to guarantee a minimum price for electricity generated at a mega wind and solar farm to be built in Morocco that could power UK homes via a 3800-kilometre subsea cable.

"I will very confidently predict that over the next 15 years the world will see a huge number of interconnectors," says Simon Morrish at Xlinks of such cables.

Xlinks is also working with Australian firm Sun Cable on its proposal to build the world's largest solar farm in the north of Australia and connect it, via Darwin, to Singapore through a 4200-kilometre cable, to supply it with low-carbon electricity. In September, Sun Cable gained approval to route the high-voltage cable through Indonesian waters.

2022 may also see progress on efforts to build an "energy island" in the North Sea, which would act as a vast hub for offshore wind farms that can supply several European countries. UK company National Grid recently told *New Scientist* it is in talks about the pioneering project. ▮

JOHN WARBURTON-LEE PHOTOGRAPHY/ALAMY

Solar reflectors in Australia's Northern Territory generating power

2

ABDULHAMID HOSBAS/ANADOLU AGENCY VIA GETTY IMAGES

A BioNTech worker tests the procedures for making mRNA

Medicine

mRNA technology may treat stubborn diseases

2022 could be the year when we find out whether mRNA vaccine technology can be used for a lot more than just making vaccines. The hope is that it can also get our bodies to produce drugs that are otherwise very expensive to make, opening the door to treating a vast number of conditions.

mRNAs are essentially genetically coded recipes that tell cells in our body how to make proteins, the large molecules that form most of the machinery of life. In the case of mRNA vaccines, the mRNAs code for viral proteins that provoke an immune response.

When the coronavirus pandemic began, mRNA vaccines were still an experimental technology. There had been only a few small trials and no vaccines had ever been approved. Now, hundreds of millions of people have received the Pfizer/BioNTech or Moderna mRNA vaccines, and these have been found to be very safe and effective.

This success has given a big boost to efforts to develop other mRNA vaccines for everything from cancers to herpes. But mRNAs can code for just about any protein, so the same basic technology might also allow us to develop all kinds of treatments.

For instance, cystic fibrosis is often caused by the lack of a protein called CFTR in lung cells. Moderna and another company called Vertex are developing a potential treatment, codenamed VXc-522, that consists of mRNAs coding for the CFTR protein. The idea is to deliver them by inhalation. VXc-522 is currently undergoing safety testing and could enter human trials soon if that goes well.

Moderna is also working with drug firm AstraZeneca on another mRNA therapy, this time to get cells to make a protein called vascular endothelial growth factor. VEGF stimulates the growth of blood vessels, so this treatment, codenamed AZD8601, could be used for everything from wounds that won't heal to heart disease.

At a conference last November, the companies announced that AZD8601 had proved safe in an initial trial involving injecting it directly into damaged heart muscles during surgery. Larger trials designed to test efficacy can now get under way.

The potential of mRNA drugs is enormous. Many protein-based drugs such as antibodies made outside the body have proved extremely effective – but also extremely expensive. Antibodies have been called magic bullets with a hefty price tag, and the soaring cost of some cancer treatments has been controversial.

mRNAs could slash both development times and costs by setting our bodies to work on the difficult and time-consuming job of manufacturing the required proteins instead. ▮

Michael Le Page

> "mRNAs could slash the time and cost of drug development by setting our bodies to work"

AN IMPORTANT MESSAGE FROM PROFESSOR NICK LEMOINE MD PHD FMEDSCI, CHAIR OF THE MEDICAL RESEARCH FOUNDATION

Gifts in Wills could be the key to protecting the future of human health

Our experience of COVID-19 shows how suddenly a global health challenge can appear. As someone interested in science, you will understand that while nobody can predict what we will face next, we can be certain that the future will bring many more threats to human health.

As Chair of the Medical Research Foundation – the charitable arm of the Medical Research Council – I have seen the incredible impact that individuals who remember the Foundation in their Wills can have on the future of our health and wellbeing here in the UK. These gifts fund research and researchers which can have far-reaching implications for human health.

With a gift in your Will you can play a key role in providing the science that will protect the health of future generations.

Right now, the Foundation is funding research to tackle antimicrobial resistance, and investing in researchers like Dr Myrsini Kaforou – who will make the fight against antimicrobial resistance her life's work.

Without support at the crucial early stages, researchers like Dr Kaforou can be forced to abandon their passion and leave science altogether, with an immeasurable loss to future human health. Gifts in Wills provide the long term funding and security that allows the Foundation to invest in projects like Dr Kaforou's and lay the foundations for quality research in years to come.

Your Will can fund the rational response to health challenges that medical science provides.

> "As scientists, our duty is to secure the future of research for the generations that follow."
>
> Professor Fiona Watt, President of the Medical Research Foundation and Executive Chair of the Medical Research Council.

While we don't know what the future holds for human health in the UK, we do know that research, and the brilliant scientists driving that research forward, are the key to meeting those challenges for years to come.

Changing medicine today.
Changing lives tomorrow.
medicalresearchfoundation.org.uk

"The funding I received through the Medical Research Foundation will be transformative for my research." Dr Myrsini Kaforou

But many of these scientists rely on the generosity and foresight of fellow members of the public – people like you, who understand the power of science and are willing to leave a gift to medical research in their Wills. At the Medical Research Foundation, over 90% of our voluntary income comes from individuals who choose to include a gift in their Will – they are crucial in the Foundation's ability to fund research that will enable the next generation of scientists to make real world discoveries in the future.

I firmly believe that a gift in your Will to the Medical Research Foundation is an excellent investment and will have a lasting impact on science and on the future of human health in the UK.

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Professor Nick Lemoine MD PhD FMedSci
Chair of the Medical Research Foundation

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Medicine

Alzheimer's drug debate

Controversy over the first drug designed to treat the cause of Alzheimer's will continue, reports **Clare Wilson**

KAYANA SZYMCZAK/NEW YORK TIMES/REDUX/EYEVINE

A participant in a clinical trial for aducanumab

EXPECT to see debate over a new medicine to treat Alzheimer's disease, called aducanumab, continue into 2022. Approved in the US last June, it is the first drug designed to treat a possible cause of this form of dementia, rather than the symptoms.

Aducanumab targets beta-amyloid, a protein that makes up plaques in the brain often seen in people with Alzheimer's disease. But the drug has its critics as well as its cheerleaders. It hasn't so far been proven to reduce memory loss and confusion, the chief symptoms of Alzheimer's disease. Other commonly used medicines slightly alleviate these symptoms, but they don't work for everyone and their effects wear off.

The US drug regulatory body, the Food and Drug Administration (FDA), approved aducanumab for use to combat early Alzheimer's on the basis that it reduces the extent of amyloid plaques. These have long been seen as a "biomarker" of Alzheimer's – in other words, a biological indicator of disease progression or severity.

Other medicines have been approved on the basis of biomarkers – for instance, levels of "bad cholesterol" are seen as a biomarker for heart disease. But for Alzheimer's, it is still being debated if plaques are a valid biomarker.

There is growing concern that they may not be a cause but something more like a side effect of the disease process. Targeting the plaques is "reasonably likely to have a clinical effect", says Susan Kohlhaas at Alzheimer's Research UK. "But that's still to be tested."

When the FDA approved aducanumab, it went against the recommendations of its scientific advisory panel, which it usually follows – none of the 11 members considered it ready for approval and three members resigned in protest. The agency's acting commissioner has since asked for an investigation to take place into the approval process.

The drug's maker, Biogen, told *New Scientist*: "The approval of aducanumab by the FDA came after an extensive development, clinical testing and regulatory review process, supported by data of more than 3000 patients who participated in our trials."

"We have to leave no stone unturned in our search for treatments"

One clinical trial showed that about 40 per cent of people on the drug experienced brain swelling or bleeding visible on a scan.

The FDA has said aducanumab should now be tested in a larger clinical trial, but in practice these can take many years to produce results. Few people may want to be in a placebo-controlled trial and risk taking dummy pills after the drug has been approved.

On 17 December, the European Medicines Agency decided not to approve aducanumab. It is also under review by the UK's Medicines and Healthcare products Regulatory Agency.

If the drug is approved in the UK, it would need to be assessed to decide whether it is cost-effective for use by the national health services. In the US, it is priced at $56,000 a year.

"We have to make sure that we leave no stone unturned in our search for life-changing treatments," says Kohlhaas. "It's important to respect the regulatory process that happens in the UK and elsewhere. We also need to make sure that our treatments are evaluated for safety and effectiveness." ▮

4

Particle physics

The Large Hadron Collider comes back online

THE Large Hadron Collider (LHC) at CERN near Geneva, Switzerland, will start running again after a three-year shutdown and delays due to the covid-19 pandemic. The particle collider – known for its role in the discovery of the Higgs boson, which gives mass to all other fundamental particles – will return in 2022 with upgrades that give it a power boost.

Work has been under way to conduct tests on the collider and calibrate new equipment. Now, it is gearing up for experiments that could give physicists the data needed to expand the standard model, our best description of how particles and forces interact.

Phil Allport at the University of Birmingham in the UK says the upgrades could allow new measurements that give us insight into the way the Higgs boson decays, leading to a better understanding of how it fits into the standard model.

"These measurements shed light on what's happening at the highest energies that we can reach, which tells us about phenomena in the very early universe," he says. They will also allow us to test ideas that try to account for things that aren't fully described by the standard model, he says.

This includes mysteries that have plagued physicists for decades, such as the so-called hierarchy problem, which deals with the vast discrepancy between the mass of the Higgs and those of other fundamental particles, plus dark energy and dark matter, the unexplained phenomena that make up most of the universe.

"All of these things require extensions to the standard model of particle physics to accommodate, and all of those theories make predictions. And the best place to look to test those predictions is usually in the highest energies achievable," says Allport. He says the LHC upgrades also pave the way to entirely new observations that signal a departure from the standard model.

Part of the upgrade work has been to increase the power of the injectors that supply highly accelerated particle beams to the collider. Prior to the last shutdown in 2018, protons could reach an energy of 6.5 teraelectronvolts, but the upgrades mean this can now be pushed to 6.8 teraelectronvolts.

Rende Steerenberg at CERN says that these more powerful beams will cause collisions at higher energies than ever before, and other upgrades in the future will also allow more particles to be collided at the same time.

There are already plans for further improvements in 2024, which will narrow the LHC's beams and drastically increase the number of collisions that take place. The 2018 run saw around 40 collisions every time a pulse of protons passed each other, but upgrades will push this to between 120 to 250. At that point, the LHC will take on a new name, the High Luminosity Large Hadron Collider, and it should begin experiments in 2028.

There are still many tests to be run before the power of the new components can be unleashed. Scientists at CERN hope to finish these by late February and then slowly ramp up to a small number of full-power collisions in May. The frequency of these collisions will be increased in June, which is when Steerenberg says "meaningful" physics will begin. ▮

Matthew Sparkes

The Large Hadron Collider has been shut down for upgrades since 2018

CERN

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Wildlife

A chance to help nature

The COP15 UN biodiversity summit will be an opportunity to protect more land and oceans, finds **Adam Vaughan**

5

AS THE world examines the outcome of the COP26 climate summit, spare a thought for conservationists trying to protect the planet's natural riches. A landmark UN biodiversity summit has been postponed three times because of the pandemic and now won't be held in person in China until April, after a first session was held virtually last October.

The delay means that, incredibly, there are currently no global goals for stopping biodiversity loss. While countries missed most of the targets set for 2020, a new set of goals for 2030 – known as the Post-2020 Global Biodiversity Framework – is still seen as essential for slowing and eventually reversing the decline of wildlife and habitats.

"I'm really hopeful that what's adopted in Kunming will help move the needle on biodiversity," says Susan Lieberman at the Wildlife Conservation Society, referring to the Chinese city where the COP15 biodiversity summit will be hosted.

Chief among the possible outcomes is a pledge to designate 30 per cent of land and oceans a protected area by 2030, building on the 2020 pledge to protect 17 per cent of land and 10 per cent of the oceans. More than 70 countries, including India and the UK, have already thrown their support behind the idea. But key nations home to biodiversity hotspots are still missing, notably Brazil, Indonesia and COP15's host, China.

There is much more on the agenda for the Post-2020 Global Biodiversity Framework to be agreed in Kunming. The "ecological integrity" of those enlarged protected areas – in other words, whether they are still functioning, healthy ecosystems – will be debated. Where to site them will come under the spotlight. And, vitally, countries will discuss how tough to be on language about reducing agricultural subsidies, some of which drive the conversion of forests to land used for palm oil, soya beans and cattle.

Negotiations were set to continue in January in Geneva, Switzerland, but those have been postponed due to the omicron coronavirus variant.

The elephant, or perhaps bat, in the room is covid-19. "We can't look at the next decade on biodiversity without looking at how we prevent the next one of these [pandemics]," says Lieberman. Research shows that degrading and destroying wild areas makes it more likely that diseases in wildlife transfer to humans.

Following in the tailwind of the Glasgow Climate Pact agreed at COP26, there will be pressure for governments to align their action on biodiversity and climate change.

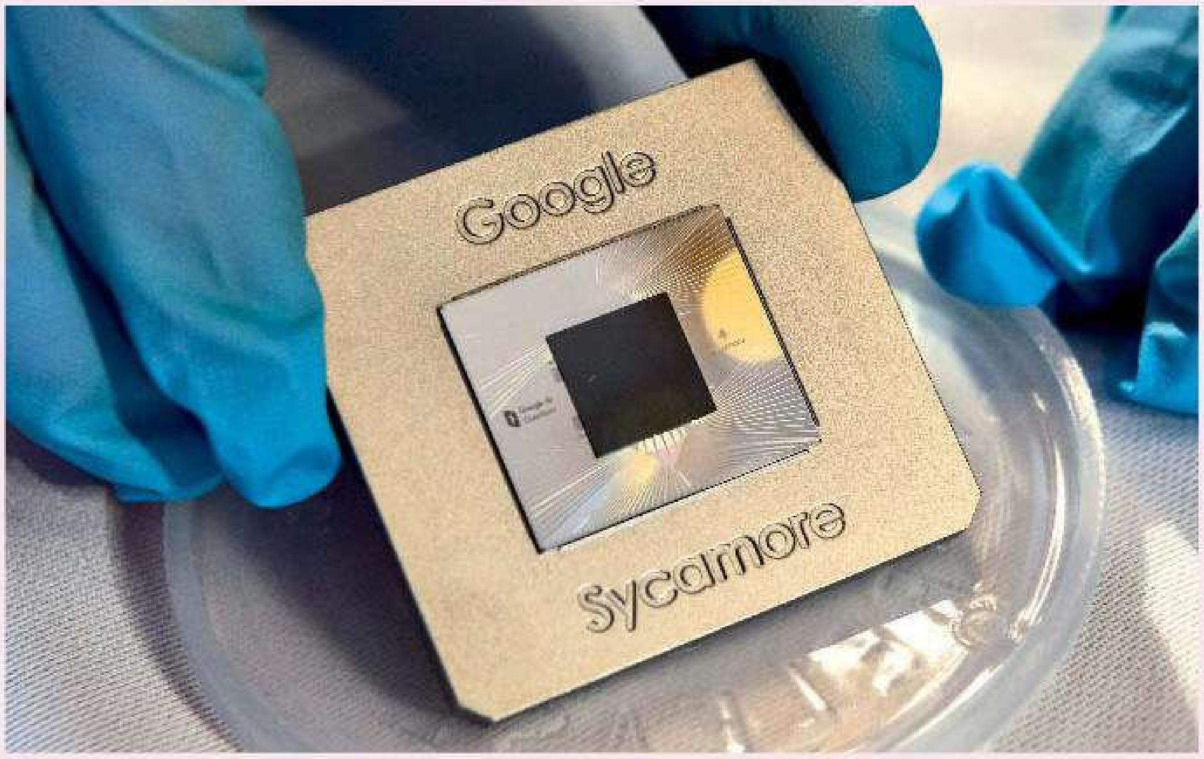
The final text of the Glasgow deal emphasised the "importance of protecting, conserving and restoring nature and ecosystems" to meet the world's goal of holding global warming to 1.5°C. And, on the sidelines of COP26, more than 100 countries agreed to halt deforestation by 2030, though it is unclear how that will happen or how they will be held to account.

One thing that government negotiators ducked in Glasgow was explicitly stating that forests, peatland, seagrass meadows and other habitats can act as "nature-based solutions" that are of "critical importance" for combating climate change. An initial draft of the pact used such wording, but all of this was later cut.

Brazil, which under president Jair Bolsonaro is keen to exploit the Amazon rainforest, is strongly opposed to the idea of nature-based solutions. The phrase features in a first draft of next year's biodiversity deal, but may well be cut in the run-up to Kunming.

A green turtle feeds on seagrass in the Bahamas

SHANE GROSS/NATUREPL.COM



PETER KNEFFEL/DPA/ALAMY

Google's Sycamore quantum processor is one of the most advanced

Quantum computing

The year of a quantum breakthrough – maybe

6

A POWERFUL quantum computer could crack encryption and solve problems that classical machines find impossible. Although no one has yet succeeded in building such a device, recently we have seen a gathering pace of progress – so could 2022 be the year?

At the moment, efforts are focused on an important milestone known as quantum supremacy: the point at which a quantum computer is able to complete a calculation that a classical computer can't, given a reasonable amount of time.

Google was first to reach this goal in 2019 using a device with 54 qubits, the quantum equivalent of regular computing bits, to perform an essentially useless computation known as a random sampling calculation. In 2021, a team at the University of Science and Technology of China solved a more complex sampling problem using 56 qubits, and later pushed it even further with 60 qubits.

But Bob Sutor at IBM says this game of leapfrog is an academic achievement that is yet to have much real impact. True supremacy will only be achieved when a quantum computer is significantly better than classical ones and is capable of solving different problems, rather than the random sampling calculations currently used as benchmarks.

He says IBM is working towards "quantum business advantage" – the point at which a quantum computer can solve genuinely useful problems for researchers or companies significantly faster than classical computers can. Sutor says this hasn't arrived yet and won't during 2022, but can be expected within the decade.

> "Quantum computers will get better over time, becoming useful in a range of applications"

Nir Minerbi, co-founder of quantum software company Classiq, is more optimistic. He believes that 2022 will see a demonstration of quantum supremacy in a useful problem.

"Remember when the first electric cars came out? They were useful to drive to the grocery store, but perhaps not to drive 300 miles to drop your kid off at college. Like electric cars, quantum computers will get better and better over time, making them useful in a wider range of applications," he says.

There are a number of hurdles to solving practical problems. The first is that devices need thousands more qubits to do so, and these must also be more stable and reliable than existing ones. It is likely that researchers will need to group them together in clumps to work as a single "logical qubit". This helps with fidelity, but will gnaw away at improvements to scale: thousands of logical qubits may require millions of physical qubits.

Researchers are also working on quantum error correction to fix glitches when they occur. Google announced in July 2021 that its Sycamore processor was able to detect and fix errors in its superconducting qubits, but the additional hardware needed to do this introduced more errors than it fixed. Researchers at the Joint Quantum Institute in Maryland later managed to pass through that crucial break-even threshold with their trapped-ion qubits.

Even so, it is early days. Scott Aaronson at the University of Texas at Austin says it would be "pretty shocking" if a general-purpose quantum computer solved a useful problem in 2022. "Error correction is just now starting to work, and we don't even seem near the point of protecting a single encoded qubit for an arbitrary amount of time, let alone doing computations on thousands or millions of encoded qubits," he says. ▮

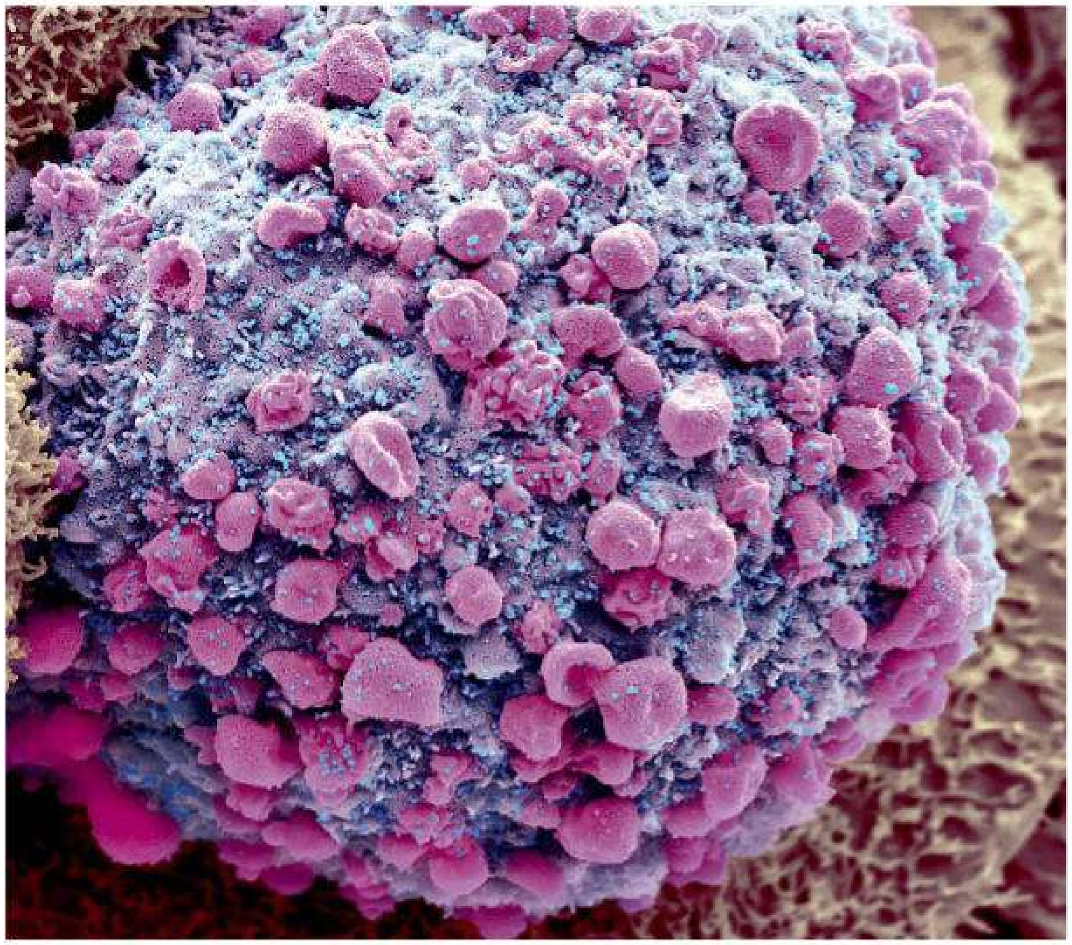
Matthew Sparkes

Covid-19

The virus will evolve further

7

More SARS-CoV-2 variants are inevitable. **Michael Le Page** reveals what to expect from them



STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY

The delta variant, viewed using an electron microscope

WE HAVE been watching evolution in action as one coronavirus variant after another emerges and triggers further waves of infections around the world. There is every reason to think this will continue during 2022 – and there is no guarantee that future variants will be any less dangerous.

For the SARS-CoV-2 coronavirus, survival is all about infecting as many people as possible. Variants that are better at spreading will outcompete other variants. A key part of this is transmissibility. When the original virus began spreading, every infected person infected two or three others on average. Delta infects six or seven. Omicron seems to be even more contagious.

It isn't yet fully understood how the virus is becoming more infectious. But with delta, it might be because it is better at replicating itself, meaning infected people shed more of the virus.

Infecting people is no longer as easy as it used to be, however. Most people in the world now have some degree of immunity because of past infection or vaccination. So variants such as omicron are evolving to evade this immunity, typically through changes in the outer spike protein, the main target of our antibodies.

There is a limit to how much more infectious the virus can become, but there may be no limit to its ability to evade our immune response. As happens with human flu viruses, we may see the continual emergence of new variants that evade immunity enough to cause wave after wave of infections.

> "Most people around the world now have some immunity from past infection or vaccination"

It is possible that, over time, different viral lineages will persist and diverge, rather than successive variants wiping out all others and sweeping to dominance. This could require different vaccines to be combined into a single dose, as is done with the flu vaccine.

It is often claimed that new viruses will evolve to cause milder symptoms. But because SARS-CoV-2 is most infectious just before symptoms appear, there is little selective pressure for it to do this. Smallpox was highly lethal and might have become worse over time. Flu still exacts a high annual death toll.

Another concern is that the virus might be circulating in several other animals, generating new variants that could jump back into people.

While it is possible that future variants may cause more severe illness in people with no immunity, most people in the world do now have some immunity. This is likely to continue to provide some protection against severe illness even if it fails to prevent infections.

But we can expect this immunity to fade over time. Even if you have already had a booster shot, you could well find yourself standing in line to get yet another jab or two in 2022 to protect you from rho, sigma, upsilon or maybe even omega. ▮

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FESTIVAL OF IDEAS

8

Space exploration

Blasting off to the moon, Mars and an asteroid called Psyche

"Psyche could be the exposed core of an ancient shattered, disrupted protoplanet"

IF ALL goes well, the first major space mission of 2022 will be the launch of the Space Launch System rocket in February. After many budget and schedule overruns, NASA's colossal rocket is finally set for its first uncrewed flight, which will carry several small satellites into orbits either near or around the moon.

They won't be the only lunar visitors. NASA has contracted private firms to send nine rovers to the moon, along with landers and other experiments. "Many of these are tests of this new idea that NASA is pushing, on whether commercial companies can deliver payloads to the moon, accepting higher risk for lower cost," says Jim Bell at Arizona State University. "It's a new paradigm for space missions, and a real renaissance in lunar robotics."

Japan and the Russian space agency Roscosmos will also send landers, and India and the United Arab Emirates are each sending a lander and rover, as are firms in Germany and the UK.

NASA has its sights set on an asteroid called Psyche, too, with plans to launch a mission of the same name in August. It will visit the strange space rock, which is made mostly of iron and could teach us how planets form and what their metallic cores are like.

"The leading hypothesis is that Psyche could be the exposed core of an ancient shattered, disrupted protoplanet. It could be a snapshot in time of planets forming early in our solar system," says Bell, a member of the Psyche team.

The mission will take four years to reach Psyche, where it will take photos, analyse the chemical composition of the asteroid and measure its interior structure and magnetic field. The aim is to figure out whether Psyche is an ancient planetary core, determine how it formed and extend those inferences to understand terrestrial planets.

Mars will also be a feature of 2022. In September, the European Space Agency and Roscosmos will launch the Rosalind Franklin rover, which should arrive on Mars in 2023. The rover will be larger than China's Zhurong rover, but smaller than NASA's Perseverance rover, both of which landed on the planet last February. It will attempt to find evidence of life in an area called Oxia Planum, which may have once been friendly to life.

Rosalind Franklin will carry several cameras and scientific instruments, but perhaps most exciting is a drill that can collect samples from up to 2 metres below the surface – far deeper than the 6 centimetre record set by NASA's Curiosity rover.

Drilling provides access to clues about the planet's past that have been lost at the surface by ionising radiation from space, says Jorge Vago, project scientist for the mission. "Over billions of years, it acts like millions of little knives, cutting away at the molecules that we would like to study to look for potential signs of life." **Leah Crane**

NASA/JPL-CALTECH

The Psyche spacecraft's propulsion system undergoes inspection

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Comment

Climate change's shadow

Polls show that global warming has rocketed up the priority list for the public, but there is still much to do, says **Adam Corner**

SIMONE ROTELLA

LAST year saw a wave of climate change coverage and record levels of public concern. One poll found that 40 per cent of people in the UK thought climate change was the most important issue facing the country, and a major 30-country study found similar results, with most people in most countries now worried about climate change. They wanted both government and personal action to address the problem. These are uncharted waters for public opinion across the planet.

This is a welcome development and it is long overdue. But it represents the start, rather than the finish line for public opinion. Dig deeper and some important planks of the transition to net zero start to look a little shakier.

UK polling in the wake of COP26 found that 62 per cent of people thought the UK – as hosts of the conference – should be one of the most ambitious in the world on climate change, regardless of what other nations are doing. But only half that number were clear on what politicians were actually offering. Internationally, awareness of plans to tackle climate change is generally low.

To avoid public concern curdling into cynicism, political leaders must visibly practise what they preach. Otherwise, worries about the costs of living – and how the price tag of decarbonisation will be shared – will be weaponised by small but noisy groups who have shifted from challenging the science to criticising the costs of transition.

In reality, the price of not acting is much greater, but the cost of transitioning to net zero must be distributed fairly or the process will quickly unravel, and here people are eager to understand what a fair role for them is.

Around the world, individuals are increasingly willing to play their part in the shift ahead. But research from the Climate Engagement Partnership shows that only 13 per cent of the UK public are clear on what "people like them" can do to reduce the country's carbon emissions. And support falls away when surveys emphasise how low-carbon policies could hit people's wallets.

Nearly 70 per cent of people in the UK support "frequent-flyer levies" in the abstract, for example, but this drops to 30 per cent if it costs them more to take a flight. In fact, a frequent-flyer levy would only apply to frequent flyers (in the UK about 70 per cent of flights are taken by 15 per cent of the population). This is all the more reason for governments to be clear about what a fair transition looks like, before misinformation and scaremongering takes hold.

In countries around the world, there are shared misconceptions about how effective different individual actions are. Most citizens typically underestimate the significance of reducing air miles, so clarity from political leaders about not only what they are doing, but what can reasonably be expected of voters, is key.

The UK-based think tank Onward created a Net Zero Index for gauging support for different policies once their likely cost, impact on carbon emissions and relative urgency are taken into account. While graduates and high earners were very supportive of net-zero policies and willing to pay higher taxes and prices, non-graduates and people in low-income and lower socio-economic groups were more hesitant.

Some take this as a sign that the public rejects net-zero policies, but it should be seen as an invitation to make the costs fall fairly. The challenges are similar globally, and celebrating record levels of climate concern is toasting yesterday's victories.

From lifestyle choices like forgoing flights, to who sees the benefit of investment in green jobs, the most important challenges for retaining public support on the road to net zero are now about getting the details right. ▮

Adam Corner is a writer and researcher specialising in climate and communication

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No planet B

A big year for wildlife China will host COP15, the UN Biodiversity Conference, in 2022, making it the most important year for the environment since 2021, writes **Graham Lawton**

Graham Lawton is a staff writer at *New Scientist* and author of *This Book Could Save Your Life*. You can follow him @grahamlawton

WHEN it comes to selecting venues for crunch talks on the future of the planet, the United Nations does a nice – if possibly unintentional – line in irony. Much was made of last year's decision to hold the COP26 climate talks in the UK, which as the cradle of the industrial revolution is arguably also the birthplace of climate change. There are similar, more recent, historical ironies in the choice of Kunming, China, for negotiations of global biodiversity targets. Kunming is the capital of Yunnan province, the most likely evolutionary home of SARS-CoV-2, a virus that has been described as the first global blowback from the biodiversity crisis.

Location does matter. The expectation is that the host nation will set the tone, lead by example and cajole other nations into going the extra mile. China has been criticised for a vacuum of leadership in the build-up to Kunming. It has a reputation as being part of the problem rather than part of the solution, with rampant infrastructure development, rising greenhouse gas emissions, poor air quality and an exploitative relationship with nature. Its most famous animal, the giant panda, has long been a symbol of endangered species. Its second-most famous, the Yangtze river dolphin, is almost certainly extinct. And it talks about creating an "ecological civilisation" while exporting its environmental problems on the back of its global belt and road project, say critics.

Although similar charges can be levelled at most Western countries, this is extremely discouraging because the talks in Kunming are crucial to the future of the natural world. They will aim to create a new agreement for the protection of biodiversity to replace the 2010 Aichi targets, which expired completely unfulfilled at the end of 2020. New targets were supposed to be negotiated early last year, but the talks were postponed due to covid-19. Right now, there are no targets, and the 2030 deadline to reverse the destruction of nature is looming.

There has been some progress. Preliminary talks in October produced a draft agreement that conservation group WWF gave a cautious thumbs-up to. Omicron permitting, negotiations will reconvene in Kunming in April and May.

There is still room for a great leap forward. China actually has a positive story to tell. It is a biodiversity treasure trove, one of just 17 "mega-biodiverse countries" recognised by the United Nations Environment Programme. To qualify, a country must have very high levels of biological diversity including many species found nowhere else; the minimum entry requirement is 5000 endemic species of plant. Between them, the 17 mega-biodiverse countries are home to 70 per cent of global biodiversity on just 10 per cent of the world's land surface. China alone has 10 per cent of all plant species and 14 per cent of animal species.

> **"China is one of 17 mega-biodiverse countries. It has 10 per cent of all plant species and 14 per cent of animals"**

Until recently, China's protection of its biodiversity has been haphazard, a patchwork of more than 10,000 often poorly managed national and regional parks under various jurisdictions. But in 2017, the government revealed plans to consolidate much of this into a system of 10 national parks. In October 2021, it announced that the first five of these were now a reality, covering 230,000 square kilometres and conserving nearly 30 per cent of the country's key terrestrial species. That includes giant pandas, Siberian tigers and leopards and the world's rarest ape, the Hainan gibbon.

This is clearly an upgrade on what has gone before. According to Guangyu Wang at the National Park Research Centre at the University of British Columbia in Canada, it represents a break from decades of policies prioritising economic growth over ecological health. It could also act as a model for other mega-biodiverse countries – notably Indonesia – to upgrade their own fragmented national park systems.

However, two of the five national parks "announced" in October already existed, and all five cover just 2.5 per cent of China's land, whereas conservation biologists (and the draft agreement) say that at least 30 per cent must be protected globally. What's more, scientists says that protecting charismatic species and environments matters less than a joined-up approach to protecting all of biodiversity.

In international negotiations, leadership matters. At COP26 in Glasgow, China kept a low profile until the latter stages when it announced a surprise deal with the US – another mega-biodiverse country – to work together on climate issues. If China can pull another panda out of the hat by inspiring the other mega-biodiverse countries to follow its lead, then the biosphere will probably be in better shape after Kunming than before it. Where there is life, there's hope. ▮

Graham's week

What I'm reading

I haven't got a copy yet (Christmas is coming) but I really want to read How to Love Animals in a Human-Shaped World *by Henry Mance.*

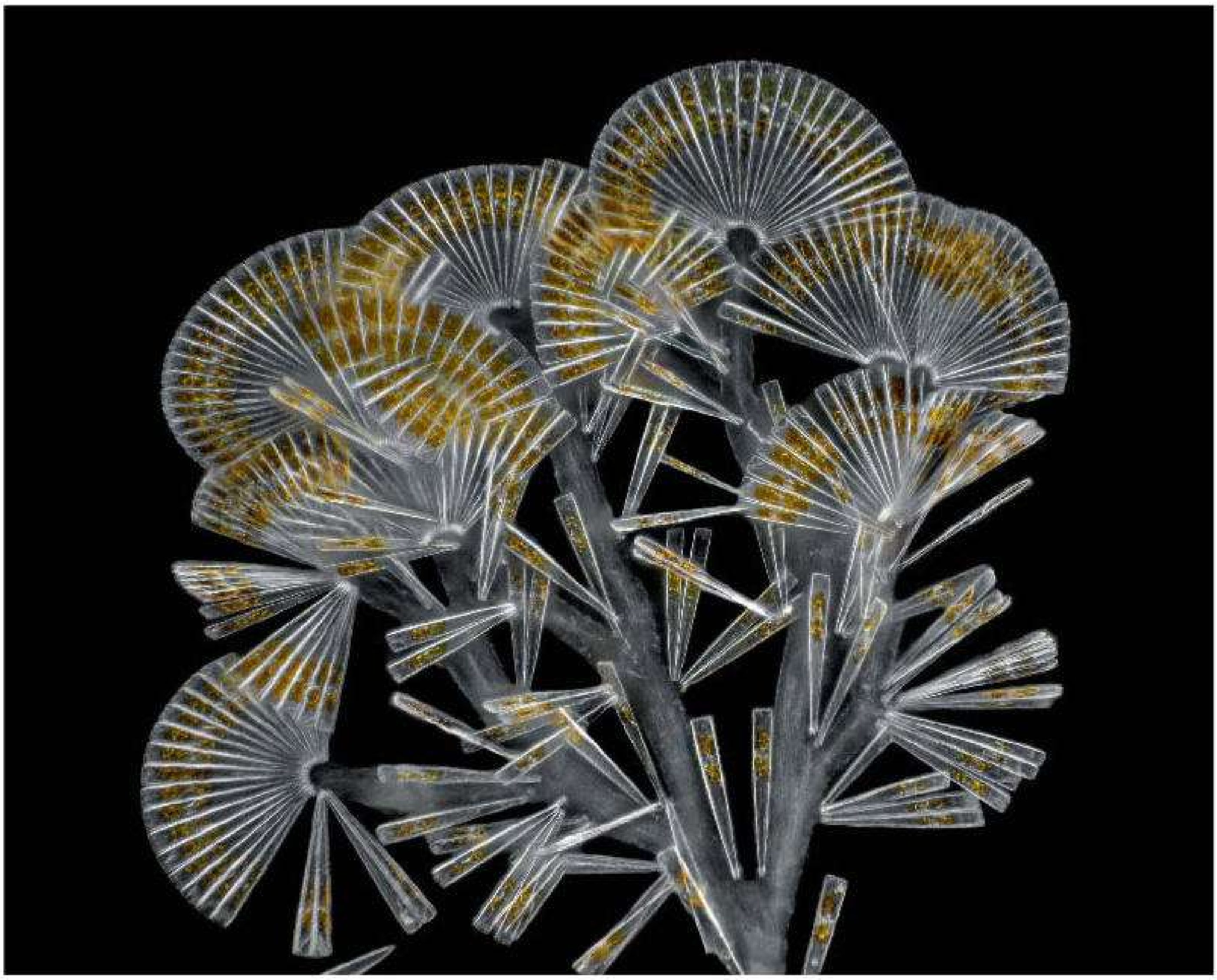
What I'm watching

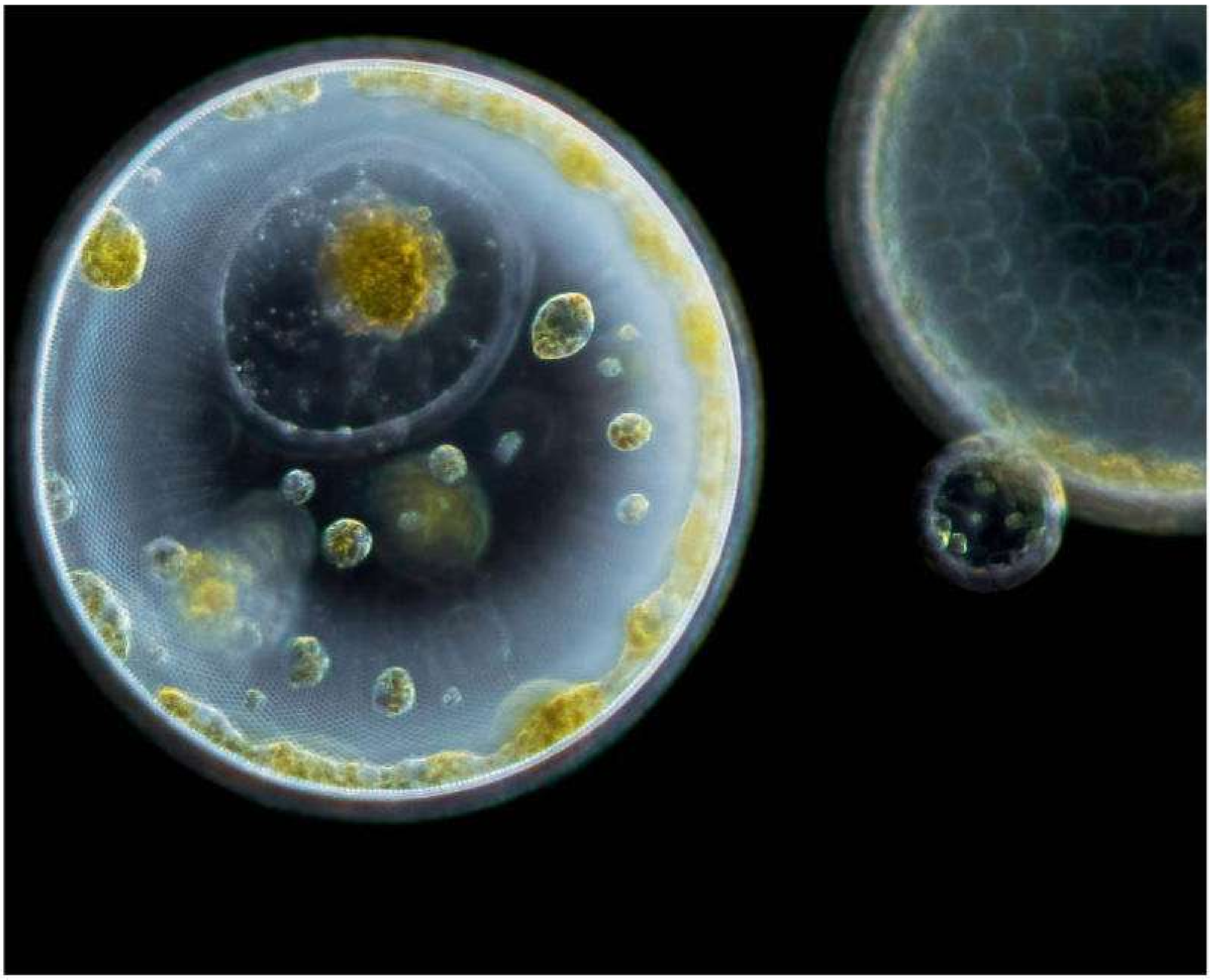
The Wheel of Time *on Amazon Prime Video. Epic escapism.*

What I'm working on

I'm fermenting a new batch of kimchi.

This column appears monthly. Up next week: Annalee Newitz





Unsung heroes

Photographer Jan van IJken

THESE mesmerising shots reveal the microscopic beauty of plankton – and their predators. They are part of a film and photo project called Planktonium by photographer Jan van IJken, who captured this diverse array of species in various Dutch waters, including puddles, lakes and seas.

Plankton form the base of marine and freshwater food webs. They consist of phytoplankton (plants) and zooplankton (animals). Their name derives from the Greek word for "drifter", since they are too tiny to fight tides or currents. Phytoplankton oxygenate the ocean through photosynthesis, enabling marine animals to thrive, and produce about half the world's oxygen.

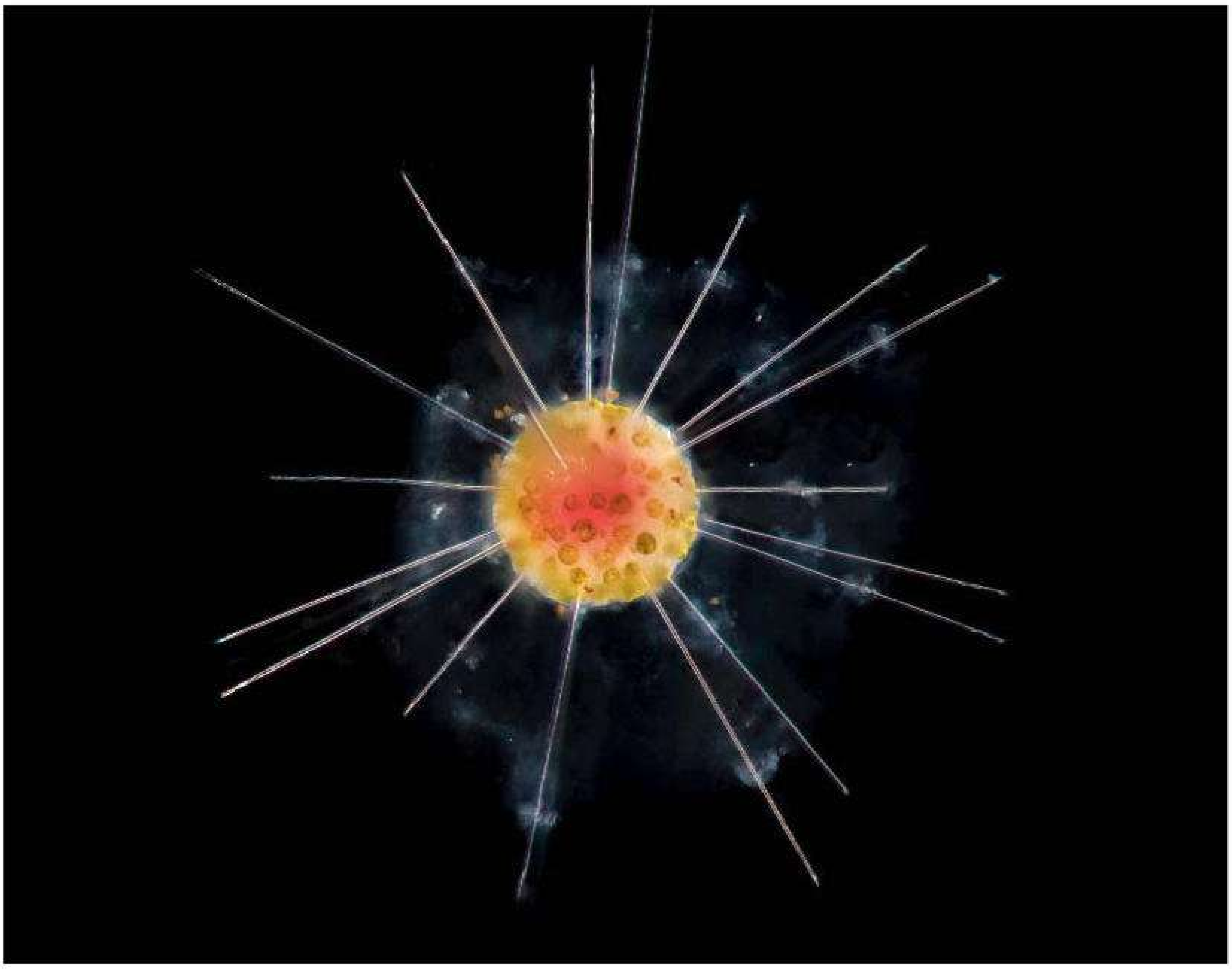
On these pages are (clockwise from far left): a larva of a polychaete worm during a stage of its life cycle when it is considered to be a plankton; a diatom phytoplankton – which have see-through cell walls made of silica – called *Licmophora flabellata*; and another diatom, *Coscinodiscus*.

Overleaf, the top-left image shows a single-celled radiolaria zooplankton, with internal skeletal structures and external spikes of silica. Below, a crustacean called a copepod gathers diatoms. Copepods feed on phytoplankton and tiny aquatic animals, and are a vital food source for larger species, such as fish. On the right is another predator of plankton, the water flea *Polyphemus pediculus*, with two eggs in tow.

Van IJken admires the "beauty, fine detail and incredible shapes" of plankton. "Their invisibility to the naked eye makes it even more interesting to observe the tiny creatures," he says.

Gege Li

Images continue on the next page



Editor's pick

Maths is a marvel full of universal truths

27 November 2021, p 25

From Caroline Wallace, London Mathematical Society

I share Michael Brooks's concerns about low levels of numeracy and high levels of "maths anxiety". But I don't think the solution simply lies in a "more utilitarian approach" to the subject. This would risk taking the wonder and imagination out of maths, which is what inspires people to keep studying it and pushing back the frontiers of our understanding.

The value of maths to society is clear. Not only have discoveries in it led, for centuries, to applications and achievements in every area of science and technology, but it is also an inherently valuable part of our shared human experience. What's more, its insights and discoveries don't just apply through time, but through space too. The same maths truths apply on the other side of the universe, just as they do on Earth.

Ensuring that the pipeline of maths talent remains healthy is why the London Mathematical Society set up the Protect Pure Maths campaign last year. This seeks to ensure that university maths departments get the funding they need and society gets the maths graduates necessary to flourish – and to help the next generation of learners avoid maths anxiety.

Asking whether maths belongs with the sciences or humanities may be a provocative and fun diversion, but the subject faces serious challenges around funding and perception. Our campaign exists to make the case for maths. We would welcome Brooks as a supporter.

Could we beat omicron variant at its own game?

11 December 2021, p 7

From William Hughes-Games, Waipara, New Zealand

When a new coronavirus variant arrives and is highly infectious, it seems to wipe out older varieties. Why couldn't we engineer a variety that is very transmissible but not deadly? Perhaps this would be better than vaccination.

We're missing a trick for making shipping green

27 November 2021, p 45

Owen Mooney, Hamilton, New Zealand

In her look at decarbonising shipping, Nicola Jones reviews multiple propulsion options for commercial vessels, but doesn't include nuclear power.

This is both the most green and most economical option for shipping propulsion. There are currently over 160 ships powered by more than 200 small reactors, according to the World Nuclear Association. Fear of nuclear power is stifling the use of an incredibly effective and carbon-free energy source. We need to use it where possible for the sake of the planet.

Fears for our future in the metaverse

27 November 2021, p 26

From Will Kemp, Wagait Beach, Northern Territory, Australia

Annalee Newitz hopes the allegedly forthcoming metaverse won't reduce humanity to "gibbering crash-heads". I assume Newitz doesn't know anyone who has been swept up into the social media-induced epidemic of conspiracy theory disinformation. I do, and it seems to me that we are already halfway there.

From Andrew Shead, Tulsa, Oklahoma, US

Excellent analysis by Newitz, one that applies just as well to science in general. If something is capable of misuse, then it surely will be so used. Beware the MetaZuckerFaceBerg – what you see is merely its innocuous-looking tip.

Put all that captured carbon to good use

Letters, 27 November 2021

From Guy Cox, Sydney, Australia

Trevor Randall advocates for carbon capture and storage. I agree with the first part (capture), but not the second.

Storing vast quantities of carbon dioxide underground is a recipe for a future environmental disaster. What's more, this is a valuable resource that should be used. We should be bubbling CO_2 into vast algal fermenters, or piping it into sealed greenhouses, to produce biofuel.

This way, we can power existing motor vehicles, planes and ships without trashing the planet to extract the scarce minerals needed for wind and solar farms and for electric vehicles.

More views on the role of kindness in human story

27 November 2021, p 38

From Adrian Cosker, Hitchin, Hertfordshire, UK

Kate Ravilious makes a powerful case that it was the benevolence and social skills of *Homo sapiens* that ensured its survival when other hominins were wiped out by environmental changes 40,000 to 50,000 years ago.

This may well be part of the story, but it rather ignores the evidence from recorded and recent history of the genocidal behaviour of *H. sapiens* to "different" members of its own species, let alone to other hominins. This dual nature – caring and keen for contact with those perceived to be "us", with the potential for genocide against those perceived as outsiders – has plagued our history and exercised the founders of religions and populist leaders who have sought to either mitigate or exploit it.

It is sadly still with us. The answer to our survival may be that our social and cooperative skills, combined with an exceptional potential for viciousness, enabled us to be more effective both at holding on and at wiping others out.

Philippe Max Rouja, Southampton, Bermuda

It warms my heart to see the idea of kindness as a driving force in the development of our species, *Homo sapiens*, becoming mainstream. There have been many dedicated anthropologists who have gathered information about other cultures that points towards this kind of hypothesis. They argued that social institutions emerged not as control mechanisms for humanity's basest nature, but were fundamentally based on a capacity for caring and kindness.

We're pretty sure a dawn raid won't be triggered

30 October 2021, p 47

From Michael Ennis, Gloucester, UK

Have any readers dared to buy *How to Blow Up a Pipeline* by Andreas Malm, whom you interviewed a couple of weeks ago? My finger was hovering over the checkout button when I realised that I live near GCHQ, the communications monitoring service for the UK's intelligence agencies. Not wanting the 5am knock on the door, I chickened out.

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For the record

- ***The Return of the Pink Panther* featured Inspector Clouseau (Almost the Last Word, 4 December)**
- **In absolute terms, black lava is about twice as hot as boiling water (27 November, p 42)**

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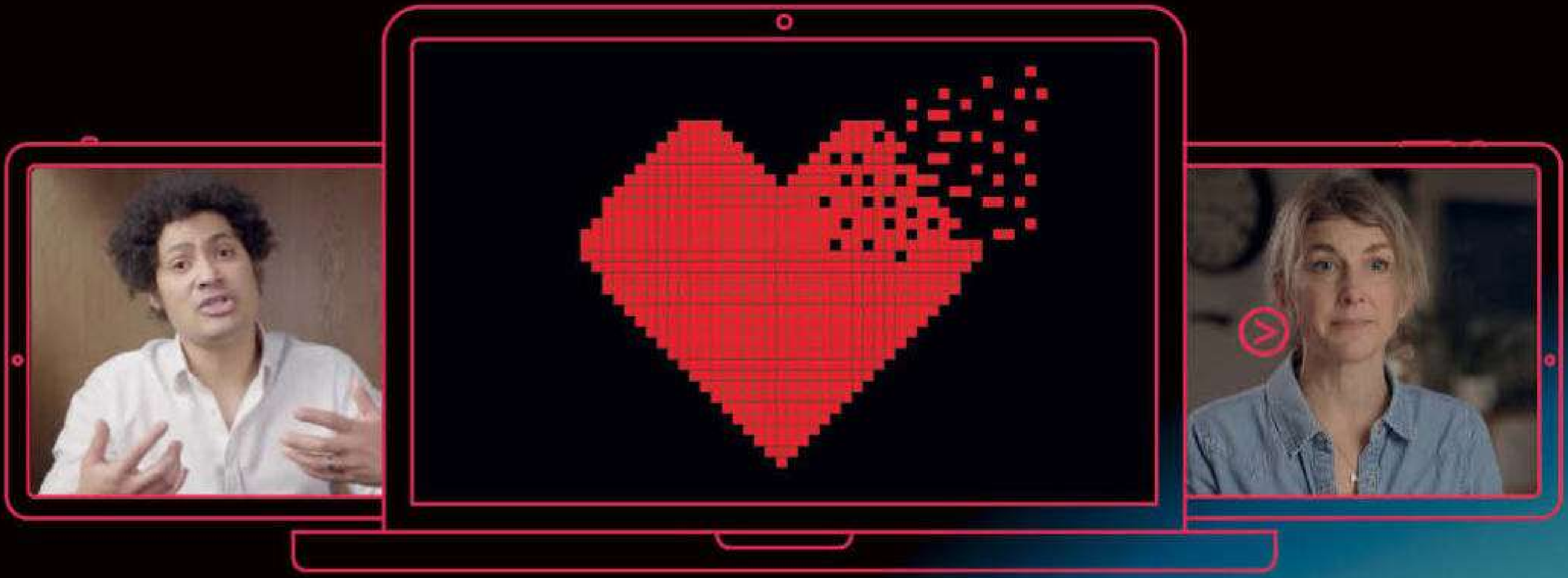

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Books for a brighter day

It's time to not only marvel at our world, but to think seriously about protecting it, says **Simon Ings** in his round-up of the best non-fiction out this year

Explore and protect

ACROSS the globe, water went wild in 2021. Floods hit everywhere from Afghanistan to New Zealand, and the UK was affected by flash floods in the summer.

So, as we begin 2022, we should take heed of Erica Gies's forthcoming book *Water Always Wins: Going with the flow to thrive in the age of droughts, floods and climate change*. She argues that, as our fields and cities sprawl, it is high time we learned to flow with water's natural rhythms.

Chris Armstrong's *A Blue New Deal: Why we need a new politics for the ocean* also calls for action. His priorities are the many challenges faced by those whose lives rely on the oceans. From the fate of nations being submerged by sea level rise to the exploitation of people working in fishing, plus the rights of marine animals to a future where they aren't at risk of extinction, he points out that there is a lot to do.

Along with the growing urgency around climate change, there is a renewed interest in the way we tell the story of life on Earth. In *The Sloth Lemur's Song: Madagascar from the deep past to the uncertain present*, environmental researcher Alison Richard traces the history of Earth's fourth-biggest island, from its origins as a landlocked region of Gondwana to its emergence as an island home to huge, flightless birds and giant tortoises, and on to the modern-day developments that now threaten its biodiversity.

Palaeobiologist Thomas Halliday embraces a yet more epic timescale in *Otherlands: A world in the making*, touring the many living worlds that preceded ours, from the mammoth steppe in glaciated Alaska to the lush rainforests of Eocene Antarctica. If you have ever wondered what sound a pterosaur's wings made in flight, this is the book for you.

Given that nearly all of the species that have lived on Earth are extinct, it might be an idea to think about what we want to preserve from our current biosphere. In *Tickets for the Ark: From wasps to whales – how do we choose what to save?*, ecologist Rebecca Nesbit wonders how we might decide the fate of Earth's estimated 8.7 million species, including ourselves. Are native species more valuable than newcomers? Should some animals be culled to protect others? And is it really our place to decide?

Feathered friends

As a species, we tend not to appreciate what we have lost until it is gone – or nearly gone. There are currently around 3 billion fewer birds in our skies than there were in 1970. And, perhaps not coincidentally, 2022 is a bumper year for books about birds.

Faced with a quite catastrophic decline in bird populations, some writers have focused on what birds mean to our lives. In *Birds and Us: A 12,000 year history, from cave art to conservation*, ornithologist Tim Birkhead laces his own remarkable travels with the story of humanity's long fascination with birds. We have worshipped them as gods, worn their feathers and even attempted to emulate their method of flight.

Even without these cultural efforts, it seems that we share many of our behavioural traits with birds: our longevity, intelligence, monogamous partnerships, child-rearing habits, learning and language all have an avian equivalent, says behavioural ecologist Antone Martinho-Truswell. In *The Parrot in the Mirror: How evolving to be like birds made us human*, he shows how, from wildly different beginnings, the evolutionary stories of humans and birds have pushed both towards many of the same solutions. Sometimes we could do worse than to think of humans as featherless birds, he argues.

PETE SALOUTOS/GETTY IMAGES

> "Birds not only have a keen sense of smell, they tweak the scents of the oils they use when preening"

Might this kind of thinking inspire us to better orchestrate our rescue and preservation efforts? Patrick Galbraith's *In Search of One Last Song: Our disappearing birds and the people trying to save them* crosses Britain on a journey that may well be his last chance to see some of our vanishing birds. On the way, he meets the people – reed cutters and coppicers, gamekeepers and conservationists – whose efforts sustain vital habitats for some of our rarest birds, but who often fall into misunderstanding and conflict with each other.

While some focus on saving birds, other books offer a chance to understand them better. Douglas J. Futuyma's *How Birds Evolve: What science reveals about their origin, lives, and diversity* traces avian species through deep time to explain how they developed such a rich variety of parenting styles, mating displays and cooperative behaviours.

Evolutionary biologist Danielle J. Whittaker's *The Secret Perfume of Birds: Uncovering the science of avian scent* adds a new feather to their cap with the news that birds not only have a keen sense of smell, but they tweak the scents of the oils they use when preening to attract mates and deter competitors. From tangerine-scented auklets to mossy-smelling juncos, birds are more fragrant than you might think.

Joys of the cosmos

Setting the wonders of Earth to one side, let's examine the mysteries of space. In *Black Holes: The key to understanding everything*, physicists Brian Cox and Jeff Foreshaw use black holes, the most enigmatic objects in the universe, to explain some very profound physics. What is information? How could gravity and quantum theory one day be unified? And what actually is empty space?

If that isn't mind-bending enough, try physicist Nicole Yunger Halpern's book *Quantum Steampunk: The physics of yesterday's tomorrow*. In it, she reimagines 19th-century thermodynamics through a modern, quantum lens, playing with the aesthetics of the 1800s through trains, dirigibles and horseless carriages. It is a physics book, but one that is as likely to attract readers of science fiction as those of popular science.

If we can't beat water, perhaps we should learn to go with the flow

If you prefer a more straightforward approach, however, pick up physicist, writer and presenter Jim Al-Khalili's *The Joy of Science*. It is a brief guide to leading a more rational existence. A little book of calm that is very welcome in these strange times.

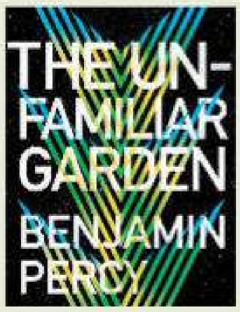
Fresh thinking

Perhaps in response to these strange times, this year features several books that look at old notions in an entirely new way. In *Am I Normal?: The 200-year search for normal people (and why they don't exist)*, historian Sarah Chaney tells the surprisingly recent history of normal people. Before the 1830s, says Chaney, the term was hardly ever used to describe human behaviour. But with the advent of IQ tests, sex studies, censuses and data visualisations, we became ever more conscious of, and anxious about, human diversity. Can we ever learn to live with ourselves?

Learning from the natural world might help in this regard. Lucy Cooke's *Bitch: A revolutionary guide to sex, evolution and the female animal* clears away our outdated expectations of female bodies, brains, biology and behaviour and challenges our ideas about sexual identity and sexuality in humans and other animals.

One aspect of life that seems difficult to argue with is the ageing process. But in *Jellyfish Age Backwards: Nature's secrets to longevity*, Nicklas Brendborg asks not just why we grow old and die, but what we can do about it. What can we learn from the Greenland shark that was 286 years old ›

Sci-fi: 10 top reads for 2022



The Unfamiliar Garden / The Sky Vault

Benjamin Percy (Hodder & Stoughton)

Not one but two sequels to *The Ninth Metal* come out this year. A comet peppers Earth with a new metallic super-ore whose discovery changes everything. Out in January and August, respectively.

Goliath: A novel

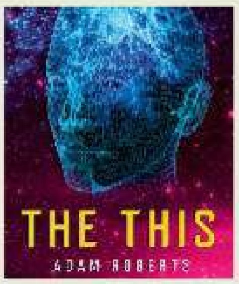
Tochi Onyebuchi (Tordotcom)

In the 2050s, space colonies offer refuge from a collapsing climate, but only for the rich. The rest have to figure out how to live in it. Out in January.

Mickey7

Edward Ashton (St Martin's Press)

Mickey7 is a disposable human who is sent to colonise dangerous new worlds, a job he is suited for because he can regenerate. After being lost, presumed dead, he meets his successor and they must team up to survive. Out in February.



The This

Adam Roberts (Gollancz)

In the dystopian near future, smartphones have become sex toys and the hottest new social media platform grows directly into your brain. What could possibly go wrong? Out in February.

The Cartographers

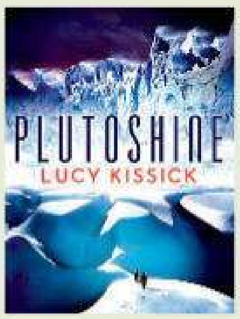
Peng Shepherd (Hachette)

In this dark fable, a young woman finds a strange map among her estranged father's things after his untimely death. Deadly secrets and gothic-inflected speculative fiction ensue. Out in March.

Plutoshine

Lucy Kissick (Orion)

Lucy Kissick is a nuclear scientist with a PhD in planetary geochemistry. Her book about terraforming Pluto – even as native alien species are discovered – may put you in mind of Kim Stanley Robinson. Out in April.



Dreams Bigger Than Heartbreak

Charlie Jane Anders (Titan)

Teenage geniuses in space. Book two of a fun, rompy, LGBTQ+ space opera series that blurs the line between young adult and science fiction. Out in April.

Eversion

Alastair Reynolds (Gollancz)

Airships, steampunk, a mysterious artefact and expeditions that keep going wrong. It's up to Dr Silas Coade to figure out why. Out in May.

Glitterati

Oliver Langmead (Titan)

An influencer comedy of horrors billed as *A Clockwork Orange* meets *RuPaul's Drag Race*. The fun kicks off when nosebleeds become a fashion trend – and it sparks a vicious fight for credit. Out in May.

Sally Adee

The best films and TV

JAMES DIMMOCK/CBS

Towards the end of 2021, a glut of movies and shows that had been delayed by covid-19 finally hit the screens. Next year, that trend continues with a plethora of sci-fi offerings.

Paramount Plus (which is due to launch in the UK in 2022) has a double treat for fans of the *Star Trek* franchise. Patrick Stewart (pictured) stars in a new series of *Star Trek: Picard*, which returns in early 2022. Later in the year, the first season of *Star Trek: Strange New Worlds* will bring back fan favourites such as Spock, Uhura and Number One.

Over in the *Star Wars* universe, *Obi-Wan Kenobi* starring Ewan McGregor and Hayden Christensen will premiere on Disney+. The streaming service will also bring back Diego Luna as Cassian Andor from *Rogue One* in *Andor.*

Back on Paramount Plus, a new show, *Halo*, based on the hit video game series, will also be released in early 2022. Set in the 26th century, it will focus on a war between humans and aliens, with Pablo Schreiber set to play the legendary Master Chief.

From *Westworld* creators Jonathan Nolan and Lisa Joy, comes a new high-concept series for Amazon Prime Video called *The Peripheral*, based on a book by William Gibson. It focuses on a detective (played by Chloë Grace Moretz) who believes that she witnessed a murder in cyberspace.

On the big screen, the threats are more tangible. February sees the release of *Moonfall*, in which Halle Berry stars as a NASA executive and former astronaut who must take action when the moon breaks its orbit and is set to collide with Earth.

Space thriller 65 is set for release in April. Few details have been released, except that the main character, played by Adam Driver, arrives on another planet to discover he isn't alone.

On a lighter note, Disney Pixar's *Lightyear* comes to cinemas in June. Set in the *Toy Story* universe, it traces the origins of Buzz Lightyear – the "real" astronaut that was immortalised as a children's toy in the cartoons.

It is also a big year for long-awaited sequels. *Avatar 2* finally arrives at the end of the year, more than 10 years after James Cameron introduced us to the world of Pandora. And *Jurassic World: Dominion* will roar onto big screens in June for one last adventure starring Chris Pratt and Bryce Dallas Howard.

Whatever else this year brings, we certainly won't be short of entertainment.

Swapna Krishna

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when the Titanic sank and is still going strong; from the many living things that have never evolved to die, and succumb only through unfortunate circumstances; or from one species of jellyfish that can revert back to its polyp stage when threatened and, remarkably, "age again"?

A related question is how bodies, communities and systems regenerate. This is a pressing issue in regenerative medicine, in developmental biology and in neuroscience. In *What Is Regeneration?,* philosophers of science Jane Maienschein and Kate MacCord point out that this rapidly growing field of study also promises to transform our ability to understand and repair the damage to ecosystems brought on by climate change.

In an acid test of our willingness to see clearly and embrace reason, there is *Endless Forms: The secret world of wasps*, behavioural ecologist Seirian Sumner's bid to make us love an animal that is older, cleverer and more diverse than its cuddly cousin the bee. Learning that nearly every ecological niche on land is inhabited by a wasp, and that there are wasps that live inside other wasps, may make you fall in love with the things. But then again...

Observation points

Another component of great science is, of course, observation – a skill we should all nurture if we want to appreciate our brief time on the planet.

Rolf Sachsse, a curator based in Bonn, Germany, has gathered together the very best of the remarkable work of English botanist and photographer Anna Atkins (1799-1871) in *Anna Atkins: Blue prints*. It is a sumptuous celebration of the sort of close observation that contributes so much to both science and art. Atkins used the then recently invented "cyanotype" process to photograph algae and ferns, thereby creating the first photo book in history.

Barriers to good observation are more often social than practical. History isn't short of remarkable female astronomers, but before the 1960s, women invariably needed the right relative or the right husband to champion and support their work. *The Sky Is for Everyone: Women astronomers in their own words* is a testament to the period that all changed. Edited by astronomers Virginia Trimble and David Weintraub, it is an inspiring anthology of writings by trailblazing female astronomers from 1960 to today.

> **"What can we learn from the shark that was 286 years old when the Titanic sank and is still going strong?"**

And finally: close observation, fresh thinking and a concern for the environment all come together in *Dust: A history and a future of environmental disaster* by Jay Owens – for my money, the most enticing of the books we know are due in 2022.

Owens explores dust as a method for seeing the world anew, from space dust to sandstorms, from the domestic to the digital and from efforts at industrialisation to the latest speculative technologies for cooling the planet. Though dust may often be the harbinger of environmental disaster, Owens, like many of the writers here, still makes room to draw out stories of hope, of salvage and of repair. ▮

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ANTONIO SORTINO

The indulgence effect

Changing the way we perceive healthy food may be the secret to successful dieting, finds **David Robson**, thanks to an ironic consequence of the mind-body connection

IF YOU are craving a satisfying dish but trying to be careful about your weight, few things are more dispiriting than reading the "healthy" options on a food menu. Words like "light", "wholesome", "skinnylicious", "sensible", "mild" – the adjectives that often accompany low-fat, low-carb options – hardly prepare you for a pleasurable meal.

One obvious consequence is that it makes the foods seem less desirable, so you may be more tempted by indulgent choices: the "rich", "flavourful", "delicious" dishes. But the influence of these words can stretch far beyond our immediate decision-making.

The way we think about food can powerfully influence our satiety long after we have finished eating, and thanks to the mind-body connection, it can even shape our hormonal responses and the meal's passage through the gut. As a result, our expectations around food can determine whether we will experience greater hunger pangs afterwards and find it harder to resist snacking later in the day. And this is all down to the sense of deprivation created by the way the food was described, irrespective of the number of calories actually consumed.

No wonder dieting is often so agonising: our culture has led us to associate healthy eating with greater hunger, and that becomes a self-fulfilling prophecy. Fortunately, as I describe in my book *The Expectation Effect*, there are many ways to change our food mindsets, and they all centre on the idea that pleasure is an essential ingredient for any weight-loss regime. As paradoxical as it may seem, cultivating an indulgent attitude to food may be the best way to control your waistline.

It was a man called Henry Molaison who provided some of the first clues to the ways our mind can influence our appetite. In the early 1950s, Molaison underwent experimental brain surgery to treat epilepsy, but the operation caused irretrievable damage to his hippocampus. As a result, he could no longer form new memories, leading him to live in the "permanent present tense", in the words of the neuroscientist Suzanne Corkin.

Observations of Molaison's behaviour helped to revolutionise our understanding of memory. They revealed, for example, that we can learn skills unconsciously without being able to recall the lessons themselves.

Less well-known, however, is Molaison's seemingly bottomless stomach. In the 1980s, Nancy Hebben at Harvard University asked him to rate his satiation on a scale from 0 (famished) to 100 (completely full) before and after his meals. If appetite were mostly directed by signals from the stomach, you would have expected Molaison's ratings to have risen after his meals. Yet they barely shifted.

To test whether his memory deficit would change his eating behaviour, the scientists performed a dinner-time experiment. After he had finished his meal, they cleared the table, and, within a minute, offered another plate of food. Amazingly, he ate nearly all of it – and, despite having consumed almost twice as much as normal, he reported only a moderate increase in his satiety.

How could this be? There is little doubt that appetite is influenced by "bottom-up" signals in the digestive system, such as a feeling of stretch in the muscles of the gastrointestinal tract, and feedback from chemical sensors that can detect the presence of nutrients. The experiences of people with amnesia like Molaison, however, suggest that we also rely on "top-down" sources of information – such as our memories of what we have eaten – to make sense of those cues, create the overall feelings of satiety and hunger, and to control subsequent food intake.

Amnesia may offer extreme examples of these processes in action, but further research has shown that we are all susceptible to top-down influences on our appetite. Even mild forgetfulness seems to increase someone's chances of overeating, while prompts to recall a previous meal curb people's snacking.

In one notable experiment, Suzanne Higgs at the University of Birmingham, UK, invited a group of students into her lab to perform a taste test on some cookies, which, after completing a couple of questionnaires, they were free to consume. Higgs found that prompting the subjects to remember their lunch, by spending a few minutes describing what they had eaten, caused them to eat about 45 per cent less – around four cookies – than participants who wrote about their general thoughts and feelings, rather than their meal memory. This wasn't the case for participants who wrote about a meal from the day

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> **"People who ate a 'healthy' chocolate-flavoured bar felt hungrier afterwards than people who had eaten nothing at all"**

before – a more distant event that would have little effect on their feelings of satiety in the moment. Instead, it was expectations of current satiety, based on the recent memory, that mattered.

Mind over menu

Aside from memory, other contextual factors seem to shape our expectations of satiety, including the information we are given about a meal's contents. Researchers at the University of Aberdeen, UK, invited 26 people for an omelette breakfast on two occasions. Before they ate, participants were shown the ingredients. This was, ostensibly, to check whether they had any allergies – but the real purpose was to change their expectations. On one occasion, they were shown two eggs and 30 grams of cheese; on the other, they were shown four eggs and 60 grams of cheese.

In reality, the participants all ate the same portions – three eggs and 45 grams of cheese – for both breakfasts. But the initial presentation did affect their subsequent appetite. People who had seen the smaller pile of ingredients subsequently ate more pasta from a buffet at lunchtime than those who believed they had already consumed a hearty meal.

Similar patterns could be seen in people drinking smoothies. In another small study, participants who thought they had consumed a large quantity of blitzed fruit tended to be less hungry over the following 3 hours than those who had seen a smaller portion.

Of course, we don't always get to see the original ingredients in meals, especially in ready-made food, but labelling can influence our appetite through similar mechanisms. Many people associate the word "healthy" with "unfulfilling", for instance, which reduces their expected satiety (see "What's your food mindset?", left). When a group of study participants were each given a "healthy" chocolate-flavoured protein bar, they subsequently felt hungrier than people who had eaten the same bar when it was labelled "tasty". Indeed, the association was so strong that they felt hungrier than people who had eaten nothing at all.

What's your food mindset?

The way we think about what we eat determines how satisfying we find certain foods, with knock-on effects for our weight.

Consider the following questionnaire. On a scale of 1 (strongly disagree) to 5 (strongly agree), do you think that:

- **There is usually a trade-off between the healthiness and tastiness of food**
- **There is no way to make food healthier without sacrificing taste**
- **Things that are good for me rarely taste good**

Researchers have found a correlation between responses to these statements and people's propensity for weight gain: the more strongly they agree with these three statements, the greater their body mass index tends to be.

In the past, some people might have imagined that this was because of low self-control – they simply didn't want to give up the pleasure of food. But these kinds of attitudes may create an expectation effect on people's appetites, so that the mere sight of "healthy" on a food label sets someone up for lower satiety after they have eaten a lower calorie meal (see main story). This would leave them feeling hunger pangs, making dieting much harder.

TV dinners could lead you to forget what you have eaten and feel hungrier as a result

MIODRAG IGNJATOVIC/GETTY IMAGES

M-PRODUCTION/ALAMY

Menus that describe food as being indulgent and enjoyable could help people who want to lose weight

It is easy to assume that these effects are simply a subjective assessment of our hunger based on what we think we have eaten, a trick of the mind that leads us to consume more. But remarkably, these expectation effects also alter our physiological responses to food. Of particular interest in this field is the "hunger hormone" ghrelin, levels of which tend to rise before a meal and drop straight after. The higher its levels, the stronger the urge to eat.

In the early 2010s, Alia Crum, now at Stanford University in California, invited 46 participants into the lab on two occasions to try out different recipes for a shake. One was labelled in big letters as "Indulgence: decadence you deserve". The accompanying description emphasised the "smooth, rich and delicious" flavours and textures, and on the nutritional information, it claimed 620 calories in total (270 of which came from fat). The other was called a Sensi-Shake. It was "light", "sensible" and offered "guilt-free satisfaction" in only 140 calories. In reality, the shakes on both days were exactly the same, containing 380 calories each.

To measure people's ghrelin responses to these manufactured expectations, Crum's team took blood samples at regular intervals before and after people read the marketing material, and after they had drunk the shakes. For the indulgent shake, the ghrelin levels changed exactly as you would hope after a meal, dropping in line with the expected effects on their hunger. For the guilt-free shake, however, the ghrelin levels barely changed at all.

Since then, further studies have shown that our expectations of satiety can also influence the release of a hormone called glucagon-like peptide 1 (GLP-1), which suppresses appetite. Given that ghrelin and GLP-1 can both bind to neurons in the hypothalamus, it shouldn't be surprising that expected satiety correlates with activity in this key brain region, which is known to control the body's overall energy intake and expenditure.

No more 'light'n'low'

Our expectations can affect the movement of food through the gut, too. In one ingenious experiment, participants were told that a cherry-coloured drink would turn to solid in their stomach. The manipulation seemed to shift the participants' expected satiety, with one saying that "I feel like I swallowed a rock!" Using a chemical tracker in the drinks, the researchers found that the food then took longer to travel from the mouth to the large intestine – which may have contributed to their sense of fullness. And participants ate less later in the day than those who believed, rightly, that the drink had remained a liquid.

We don't yet know the full consequences of our food mindsets, besides their role in shaping appetite. But it is possible that these hormonal and neurological changes also determine how quickly the body burns calories or stores them as fat. If so, they could affect our weight.

Restaurateurs and food manufacturers should take note of these findings and change the way they frame health foods. As Crum and her colleagues have pointed out, you could easily spice up the descriptions of vegetable dishes, say, with sensual and emotive language that evokes indulgence and enjoyment: "zesty ginger-turmeric sweet potatoes" or "sweet sizzlin' green beans and crispy shallots" in place of "cholesterol-free sweet potatoes" and "light 'n' low-carb green beans and shallots". Apart from making the vegetables more appetising, it should also help to ensure the consumer feels fuller for longer.

As we wait for our broader food culture to change, there are plenty of ways that we can start to apply this research ourselves. Many weight-control plans involve some form of calorie restriction, and a number of psychological principles can ease that process.

If you are looking to lose weight, one easy step would be to avoid liquid calories. Multiple studies show that we expect liquids to be less satisfying than solid foods, even if they have the same calorie content. You may feel fuller after eating pieces of fruit than after drinking a smoothie, for example. High-sugar sports recovery drinks are a particular example of something that contains more calories than your body would expect. The liquid form, combined with the health-focused labelling, means that these drinks are even less likely to reduce your appetite than solid food, so you may try to make up for the perceived deficit with snacking. The same goes for meal replacement shakes and smoothies that are billed as providing a balanced meal in a drink, and often touted as "light" or "low carb".

A second step would be to pay more attention to the taste and textures of what you are eating. It can be tempting to think, if you are on a diet, that you have to sacrifice your enjoyment of food, but the research on mindsets shows that excitement and anticipation of meals matters more, not less, if you are trying to lose weight. A meal should feel more satisfying if you choose foods with more intense flavours and make an effort

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Missing nutrients

Our attitudes to food affect how full it makes us feel (see main story), but they could also influence our absorption of vitamins and minerals, according to an experiment from the 1970s. A group of researchers studying iron deficiency in a Thai population gave people a meal in one of two forms: a traditional Thai vegetable curry and a "homogenised" version put through a food processor.

The results were astonishing. On average, people absorbed 70 per cent more iron when the meal was presented in its traditional form than when it was a homogenised paste.

To see whether the effect endured across cultures, the researchers performed the same test on Swedish participants eating a stereotypically Western meal, a hamburger served with mashed potatoes and green beans. Again, iron absorption was higher when the food was served as a recognisable meal rather than a puree. This is surprising since the nutrients should, if anything, have been more readily available to the digestive system when they were presented in the mushy paste. Instead, it appears to be the sense of anticipation for the food – whether it seemed appetising or not – that influenced the absorption.

BOONCHAI WEDMAKAWAND/GETTY IMAGES

10'000 HOURS/GETTY IMAGES

with the presentation so the meal feels like a treat. According to this research, the very worst thing you can do is to eat something insipid that leaves you feeling deprived, just because it has slightly fewer calories than a more appetising option. You will just want to eat more.

It is also worth considering the effect on the mind-gut connection of activities that distract you from the experience of eating. If you watch TV or work during meals, you won't appreciate the food going into your mouth, and may not even remember how much you have eaten later. As Higgs points out, you may be in a very similar situation to people with amnesia. It is a cliché, but eating slowly and taking care to chew each mouthful can improve the orosensory enjoyment of what you are eating, which can in turn trigger a greater hormonal reaction to the food and leave you feeling fuller for longer.

A sense of indulgence seems equally important if you have a treat. In a Canadian and French study from 2016, researchers first encouraged participants to vividly imagine the taste, smell and texture of various sweet treats. The participants were then asked how much they wanted of a delicious-looking chocolate cake. You might expect that picturing these tasty delights would have increased people's lust for cake, leading them to opt for a bigger slice. But most of the participants showed the opposite reaction. They were more likely to select a smaller portion than those who hadn't been primed to think about the sensory qualities. That may seem far-fetched, but various studies have shown that greedily imagining a treat can help people curb their eating.

A sense of celebration will help to control what you eat

Ultimately, if you want to reduce how much you are consuming, the aim should be to realise that you can get all the pleasure you need from fewer mouthfuls, so that you choose a small portion and feel less tempted to snack later on. Whether you are eating a salad or a chocolate bar, a sense of celebration will help you to control your calorie intake.

Let's be clear: you can't turn a lettuce leaf into a feast with the power of your mind. A crash diet is unlikely to be much easier with these small psychological steps, and they can't give you carte blanche to eat whatever you like. For regimes that involve a reasonable reduction in calories over a long and sustained period, however, these small mental shifts could certainly help. With the right mindset, we can sometimes have our cake and eat it, and still meet our health goals. ■

David Robson is a science journalist in London. His new book *The Expectation Effect: How your mindset can transform your life* is out on 6 January

For peat's sake

Exploitation has decimated the world's carbon-storing peatlands. The race is on to restore them, finds **Alasdair Lane**

JANI RIEKKINEN/EYEEM/GETTY IMAGES

Finnish peat bogs that were drained for forestation are now being restored

LIKE much of Europe, Finland was left economically bereft by the second world war. It needed to ramp up productivity fast and the government decided the answer was forestry, the country's industrial backbone for generations. Vast tracts of peatland were drained and trees planted, blanketing the swampy ground that covers nearly a third of the country. "These sites are incredibly carbon rich and often have high levels of biodiversity, but they're not always the best for growing trees," says Antti Otsamo. Unfortunately, by the time this became clear about half of Finland's peatland had been degraded.

Environmentally, this posed a serious problem. Without enough water, layers of peat were exposed and easily eroded, leaching carbon dioxide into the air and adding to global warming. Metsähallitus, the group that manages Finland's state-owned forests, realised that planting trees in such places was no longer an option. Today, it is committed to a different goal: restoration. "If we get the peatlands back underwater, it means the carbon remains in the soil," says Otsamo, manager for sustainable development at Metsähallitus. "Over time, the natural vegetation will return, drawing carbon

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from the atmosphere like a sponge. That's what we're trying to do now."

Finland isn't alone. Worldwide, about a fifth of peatlands have been drained, burned or otherwise damaged to make way for forests, farms and infrastructure, or extracted as fuel. This degradation generates a whopping 5 per cent of all anthropogenic greenhouse gas emissions – more than four times as much as the UK. So peatland restoration could play a pivotal role in climate regulation. This realisation is now driving conservation efforts from the Arctic to the tropics.

Although mostly found in the more northerly reaches of the planet, peatland is present in almost every country. It takes a variety of forms from bogs and moors to swamps and fens, but all are made of partly decomposed organic matter – mostly from plants – in waterlogged, low-oxygen, highly acidic conditions. These soils may have accumulated over millennia and can be metres thick, making peatland one of the most space-effective carbon stores of all terrestrial ecosystems. Despite covering just 3 per cent of the world's surface, it contains nearly a third of all the carbon in soil – twice as much as is stored in the world's forests.

Rapid release

These huge reserves of carbon re-enter the atmosphere at an alarming pace when peatland is drained. "The carbon goes in slowly, but comes out fast," says Hans Joosten, secretary-general of the International Mire Conservation Group. "Damaged peatlands lose around 10 times more carbon than healthy ones can sequester. If the current levels of peatland emissions continue as they are, they will contribute an increase of around 0.1°C to global temperatures in the coming decades."

Stalling this is the top priority for peatland conservationists, and UK scientists in Scotland are at the sharp end of global restoration efforts. One fifth of Scotland's surface is covered by peat bogs, 80 per cent of which have been degraded – in part the result of an ill-fated tree-farming programme in the 1950s. "The fundamental aim is to restore the land's hydrology," says ecologist Ian McKee at Forestry and Land Scotland, which manages the country's forest estate. "We're trying to get them to a condition where they mimic peatlands that have never been modified."

> **"Peatland contains twice as much carbon as all the world's forests"**

In the far north-west of Scotland, conservationists block drainage channels to restore a bog's hydrology

ROXANE ANDERSEN, ENVIRONMENTAL RESEARCH INSTITUTE, UNIVERSITY OF THE HIGHLANDS AND ISLANDS

The first step is often to install "peat dams", which entails blocking drainage channels to prevent run-off using huge chunks of healthy peat borrowed from a nearby part of the bog. Some locations demand a more intensive approach. Where the terrain is pockmarked with ploughed ridges and furrows, specialised machinery is used to smooth out the ground, reducing the overall surface area. In other cases, restoration teams engage in stump flipping – crushing excavated tree stumps into the soil upside down – while backfilling trenches to block subsurface cracks in the peat. "With all of this, the goal is to get the water table high enough for the natural vegetation to return, particularly the peat-building plants," says McKee.

Of these, the most important are sphagnum mosses. Synonymous with northern peatlands, coppery-green sphagnums carpet the surface, thriving in the low-oxygen, acidic conditions. Highly absorbent, these plants can soak up more than eight times their weight in water, helping to keep the surrounding soil saturated. This, in turn, slows the decay of other plant material – aided by compounds within the cell walls of the moss. This organic matter compresses downwards over time to form peat. McKee and his colleagues have found that vegetation recovery can be relatively quick, but it takes a minimum of 10 years for a revived bog to stop emitting CO_2.

To date, about 250 square kilometres of degraded Scottish peatland have been put on the road to recovery. The goal is to restore 10 times that area by 2030. If that ambition is to be realised, measuring the success of ongoing restoration projects, and deciding where to site new ones, is fundamental. "If we're going to be able to restore degraded peatlands, we first need to know where they are, and what state they're in," says Roxane Andersen at the University of the Highlands

VLADIMIR MELNIKOV/ALAMY

> **"It takes at least 10 years for a revived peat bog to stop emitting carbon dioxide"**

and Islands in Inverness, UK. "Likewise, with current monitoring programmes, we need to know what effect the work is having."

One part of the answer is interferometric synthetic aperture radar, or InSAR. Bouncing radio waves between the surface of Earth and a satellite orbiting about 700 kilometres above, InSAR produces data that, once processed by environmental monitoring firm Terra Motion, can detect changes to the peatland over space and time. This can reveal long-term trends. When peatland is in poor condition, it subsides as a result of water and carbon loss, but as it recovers, the opposite occurs. InSAR has also recently been shown to measure "bog breathing" – the natural surface motion dynamics of healthy peatland as it swells and contracts in response to different environmental conditions. Such changes are then verified on the ground. "We use ground-based data on vegetation, water level, greenhouse gases and management history," says Andersen, part of a team led by David Large at the University of Nottingham, UK, that pioneered this use of InSAR. "All of this is useful for understanding how 'bog breathing' relates to peatland condition," says Andersen.

Infrastructure developments such as gas pipelines (above) and oil extraction sites (below) are a major threat to frozen peatland in Siberia

DENNIS K/GETTY IMAGES

The researchers believe their satellite methodology could, in theory, be applied anywhere. If so, this would address one of the greatest hurdles to global peat restoration efforts: assessing the size and state of peatlands over wide areas, quickly and cost-effectively. However, the use of InSAR will prove more difficult in places where dense vegetation hides the soil surface from the satellite. In South-East Asia, researchers are working on the problem and solutions can't come soon enough for conservationists in Indonesia, home to a third of the planet's tropical peatlands.

Up in flames

The country's forests cover tens-of-millions of hectares of peatland, which stores an estimated 60 billion tonnes of carbon. Decades of draining and deforestation for oil palm plantations and agriculture have left millions of hectares degraded, releasing huge volumes of CO_2 into the atmosphere. Devoid of water, parts of these damaged peatlands routinely ignite, blanketing large swathes of Indonesia and its neighbours in acrid smoke. When, in 2015, the fires reached their fiercest in living memory, nearly 16 million tonnes of carbon were emitted every day, about the same as the total daily emissions of the US. In response, Indonesia's authorities committed to restoring 2.6 million hectares of degraded peatland by 2020. But that target was missed, prompting a new deadline of 2024.

"There's a lot of work to do, which is why it's very important to develop a precise and realistic restoration plan," says Eli Nur Nirmala Sari at the World Resources Institute (WRI) Indonesia. As with restoration programmes elsewhere, re-wetting is the first priority. Then, when the water table has risen sufficiently, native vegetation can be reintroduced, starting the terrain's return to natural function. It isn't as simple as it

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Protecting pristine peatland

Just four years ago, the world's largest tropical peat swamp was identified beneath the forests of the Democratic Republic of the Congo (DRC). Covering an area larger than England, the Cuvette Centrale stores some 30 billion tonnes of carbon, making it one of the most carbon-rich ecosystems on the planet. Having only recently been detected, the peatland is pristine; a situation that mustn't be allowed to change, say experts.

"First and foremost, there is an urgent need for protection," says Dianna Kopansky who leads the Global Peatlands Initiative of the United Nations. Deforestation poses a major threat. "We know that the DRC is preparing a peatlands action plan while also preparing to lift its long-term logging moratorium, which could present challenges," she says. Trees help keep the terrain wet, providing shade from the fearsome tropical sun. Without the cover of a leafy canopy, tropical peatlands, including the Cuvette Centrale, are at risk of drying out, heightening the danger of fire and carbon outflow.

To address these concerns, in 2018 the DRC, Indonesia and the Republic of the Congo signed the Brazzaville Declaration, a pledge to safeguard vulnerable peatlands. Kopansky is also heartened to see that, globally, major corporations and private banks are starting to take investment in peatland protection seriously. "The private sector is taking note," she says. "We're seeing new sustainable funds emerging that put an emphasis on no deforestation of peat areas, no investment in drainage projects."

KEVIN MCELVANEY/GREENPEACE

Scientists take samples from the recently discovered Cuvette Centrale peatlands

sounds. Considerable fieldwork, often in difficult terrain, is required to determine how badly damaged the peatland is and to understand the distribution and dimensions of the drainage canals that must be blocked to prevent further run-off. Large blocks of concrete or wood are installed in the canals. This isn't a foolproof process, says Sari, because the barriers frequently fail to retain the water, which still escapes via underground routes.

There are also economic concerns to contend with. Although crucial environmentally, peatland recovery often means reclaiming land used for agriculture. There is an onus on restoration authorities to address this, identifying and facilitating alternative income streams for local communities, says Sari. Research by WRI Indonesia shows this can be done. "We've proved that peatland can offer economic value even when it's in a healthy, saturated state," she says. "For example, certain species of native crops can grow well in wet conditions, which means wet farming is an option."

These lessons can be applied in other areas of tropical peatland – some of which have only come to light in recent years (see "Protecting pristine peatland", left). But different solutions are required to tackle a looming crisis in the icy bogs of Earth's far northern zones, which hold around 80 per cent of global peatland carbon. Here, much of the peat lies on top of and within permafrost, a layer of perpetually frozen subsurface soil, sediment and rock. For now, this peat is a net store of carbon – with an estimated 1700 billion tonnes – but as the permafrost thaws, CO_2 escapes into the atmosphere and that is happening far faster than thought. And rising global temperatures aren't the only problem. "Infrastructure development by oil and gas companies is leading to huge peatland degradation," says Tatiana Minayeva at ecological consultancy Care for Ecosystems. "This is very dangerous because the peat serves as an insulation material that helps keep the carbon-rich permafrost below zero."

The problem is particularly acute in Russia where almost half of the country's oil and gas

NANANG SUJANA/CIFOR

Indonesia contains vast areas of tropical peatland (left) but a government scheme to drain it to create farmland (bottom right) has increased the risk of fires (right)

REUTERS/ALAMY

NANANG SUJANA/CIFOR

> **"Big industries need to acknowledge and mitigate the damage they are doing to Arctic peatlands"**

fields sit on ecologically sensitive terrain, such as peatlands. There, according to the United Nations, 15 per cent of Arctic tundra has been destroyed by transport developments. Minayeva and her team are working hard to restore damaged sites, but, she says, for real progress to be made, the businesses involved must play their part. "Ultimately, we need the big industries to acknowledge the damage that they're doing and mitigate their impact on Arctic peatlands," she says. "For this to happen, we need new regulations."

Moss transplants

Contrast this with Canada, which is home to more than a quarter of the world's peatlands, including vast tracts within the Arctic circle. There, regulations require companies operating on peat soils to have a restoration plan. This has proved highly effective. "When I started looking into the emissions from restored peatlands around 20 years ago, I was not optimistic," says Nigel Roulet at McGill University in Montreal, Canada. "I am pleased to say that our research has proved me 100 per cent wrong."

This is largely down to the country's pioneering "moss layer transfer technique", developed by researchers at Laval University in Quebec. Donor moss – mostly sphagnum – is gathered from patches of healthy peatland, then spread by mulching machines over degraded areas. The surface is then blanketed with straw to trap water vapour and keep the moss spores moist. All being well, patches of sphagnum take root after around two years. Examining such sites five, 10 and 15 years post-restoration, Roulet and his colleagues concluded that they become net carbon sinks again after a decade or so. And, 15 years in, the way the ecosystem functions is almost indistinguishable from one untouched by human activity. "It's impossible to tell that peat has been extracted, until you see the horizon and realise you're a little lower than the surrounding land," says Roulet.

Such success stories are encouraging, but if the world is to veer away from the climate cliff edge, peatland restoration must accelerate. Research published in 2020 concluded that 60 per cent of the planet's degraded peatland must be re-wetted in the coming decades, if it is to stop being a source of CO_2 by the end of the century.

It is a message that is particularly resonant in Finland, a country committed to carbon neutrality by 2035, says Otsamo. "We Finns have come on a journey, draining swamps for the good cause of growing trees, and for extraction to sustain local economies. But it's clear we need our peatlands healthy again – for now, and for the future." ▮

Alasdair Lane is a freelance science writer based in Scotland

Clock watchers

We use them to measure time's passage, but now it seems a closer look at clocks could transform our understanding of the fourth dimension, says **Miriam Frankel**

HARDZIEJ STUDIO

A CENTURY ago, two intellectual giants met to debate the nature of time. One was the French philosopher Henri Bergson, a superstar whose fans caused the first traffic jam on Broadway in New York as they flocked to one of his earlier appearances. He believed there was more to time than something that can be measured by clocks, captured by mathematics or explained by psychology. He argued that the way we experience it, with a duration and direction, could only be revealed through philosophy.

Bergson's opponent, a physicist called Albert Einstein, disagreed. After developing his theories of relativity he believed time was a physical entity, separate from human consciousness, that could speed up or slow down. Einstein thought that time was interwoven in space in a static cosmos called the block universe which lacks a clear past, present or future.

Almost 100 years later, the question of why the time we perceive is so different from the time postulated in physics is still hotly debated. Now, fresh clues are starting to suggest the devices we use to measure time might be crucial to arriving at an answer.

Those clues relate to the fact that in general relativity, clocks are incorporated into the theory as perfectly idealised objects, with smooth readings that are accurate no matter how much you zoom in, when they actually are anything but. "Clocks are physical things which are made up of physical systems, and so we kind of know that idealisation can't be right," says Emily Adlam at the Rotman Institute of Philosophy at Western University in Canada. "A more realistic understanding of clocks may ultimately be the key to understanding time."

We can measure time using anything that goes through a change – sundials use the shifting sun, water clocks tap the flow of water and even the temperature of a cup of tea can help us estimate when it was brewed. Today, we mostly use sophisticated mechanical and atomic clocks, which can measure time much more accurately than a cup of tea, because they tick reliably with a certain frequency.

Since astronomer Christiaan Huygens invented the first pendulum clock in the 17th century, we have been steadily improving the accuracy of scientific clocks, with phenomenal results. Nowadays, the most impressive machines can measure each second so accurately that they wouldn't miss a beat in 20 billion years, longer than the age of the universe. Impressive. But it turns out there may be a price to pay for such accuracy.

To produce their ticks, clocks need a source of energy. A grandfather clock must be wound up and a wall clock is powered by a battery. The most accurate atomic clocks, with ticks that correspond to electromagnetic signals given off by atoms changing energy levels, are driven by high-powered lasers.

This isn't surprising. But rather than just requiring energy to run each mechanical part, new research suggests something more might be at play. Clocks could be a type of so-called thermodynamic machine, with fundamental constraints on their performance set by the underlying physics. If this is true, not only will it mean there could be a limit to how accurately we can measure time's passing, it "will have a huge impact on how philosophers think about time", says Gerard Milburn, a quantum physicist at the University of Queensland, Australia.

We know of two types of thermodynamic machine. The first comprises heat engines – things like fridges and combustion engines – which have a maximum efficiency set by thermodynamics. The second group encompasses information storage devices, like DNA and hard discs. In these, thermodynamics tells us the cost of erasing information. If clocks are a third, it would mean there are limits on how accurately we can tell the time, due to the involvement of energy's messy cousin, entropy.

The maximum efficiency of heat engines was determined by engineer Sadi Carnot in 1824, before entropy was defined. But his calculation paved the way for the discovery of the second law of thermodynamics, which says any closed system – something that nothing can enter or leave – will increase in entropy, a measure of disorder or randomness, over time.

Low entropy means high order. If the atoms in a box of gas clustered in one corner rather than being spread out chaotically, entropy would be low. But because there are fewer ways for atoms to be ordered than disordered, making the latter more likely, closed systems – like the universe – tend towards disorder. A cup of hot tea loses heat to its surroundings, raising overall entropy, but never spontaneously heats up. This creates an arrow of time.

The second law is the only law of physics in which rules are irreversible in time. Because of this, thermodynamics is used to explain the arrow of time we perceive. But the second ›

law doesn't tell the whole picture. There is still a question of why we only ever experience time moving forwards – many physicists today argue that this is simply an illusion.

If the arrow of time in thermodynamics could be linked to the practical reality of measuring time, then thermodynamics could help explain how we perceive time after all, says Adlam. What is needed, she says, is a direct link between thermodynamics and practical timekeeping – something explaining why all clocks run in the same direction as the entropy increase of the universe. Find this link, and we might just answer some of the questions Einstein and Bergson were at odds over. In search of this connection, a handful of researchers are turning to clocks.

A few years ago, Paul Erker at the Institute for Quantum Optics and Quantum Information in Vienna, Austria, teamed up with Marcus Huber at the Vienna University of Technology in an attempt to understand what clocks really are. They started off by modelling quantum clocks, simple systems in which the flow of energy is easy to track. In a 2017 paper, they and their colleagues showed a clock made of just three atoms – one hot, one cold and one "ticking" thanks to the energy flow between the two others – should dissipate more energy the more accurate it is. This was a big step, but still purely theoretical. By 2020, they were ready to test it.

> "The way we perceive time may be physically built into the process of timekeeping"

Teaming up with researchers including Natalia Ares at the University of Oxford and Edward Laird at Lancaster University, both in the UK, the researchers built a simple pendulum clock from a suspended membrane of silicon nitride with a thickness of about 50 nanometres. "You could think of it more like a drum than a pendulum," says Laird. They made their tiny drum vibrate, with each vibration corresponding to one tick of the clock. The strength of the vibrations could be increased by applying an electric field. To determine the clock's accuracy – how regularly the ticks occurred – they connected it to an electrical circuit including a voltmeter. "It is a beautiful experiment," says Milburn.

The crux of that experiment was that the clock became more accurate as more energy was supplied to the drum. And the more accurate it was, the more entropy it produced. This was the first result to explain why clocks move forwards in time, because as they measure time, they increase entropy, an irreversible process. "This research gives a very nice explicit link between the thermodynamic arrow of time and perceptual time," says Adlam.

Carlo Rovelli at Aix-Marseille University in France agrees the work sharpens our understanding of the strict relationship between time and heat. "Simply put, if there is no heat involved, there is no way to distinguish the past from the future," he says. The research strengthens his thermal time hypothesis, which argues that time emerges from the laws of thermodynamics on the macroscopic scale of humans, regardless of what is going on at a microscopic level.

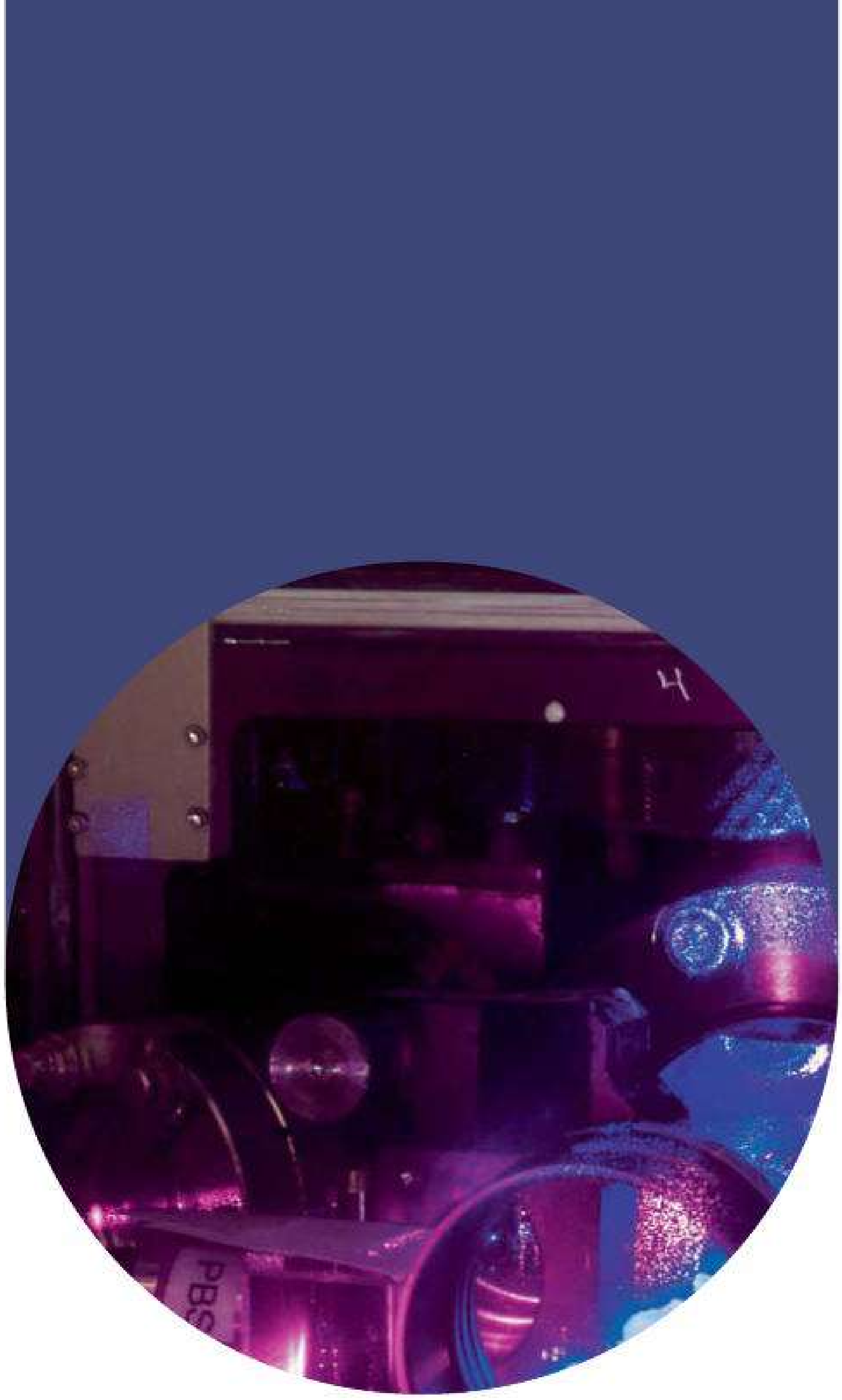
Crucially, the research also shows that the arrow of time isn't something only humans can experience. "It doesn't really matter if it's a conscious agent who observes the clock or a device, such as a detector," says Huber. The entropy still increases. "It's true for anything." Rather than being a consequence of our consciousness, this suggests the way we perceive time may be physically built into the process of timekeeping. If so, Bergson's argument falls apart and Einstein looks right to have believed time is a physical entity.

This isn't the first time a link between energy cost and the accuracy of clocks has been explored. A similar relationship between accuracy and energy cost has been seen in the biochemical clocks that operate inside ocean-dwelling cyanobacteria, helping them generate the chemicals needed for photosynthesis early in the morning before the sun rises. This is partly because they are living organisms, not mechanical clocks. "Evolution probably places additional constraints on what it means for a clock to be good, beyond the energetic constraints of precision," says Jordan Horowitz at the University of Michigan.

But not all clocks entirely follow the rules, it would seem. The most accurate atomic clocks appear more efficient than the research predicts. These clocks involve complex circuits, detectors and feedback, making their energy flow difficult to model. Both Erker and Huber are confident they will be shown to obey the same constraint.

The efficiency of engines is governed by thermodynamic laws

RIGHT: ALPEGOR/ALAMY ABOVE: MACROVECTOR/SHUTTERSTOCK



G.E. MARTI/JILA

The most accurate atomic clocks are powered by lasers

"I'm not able to prove this statement yet," says Erker. "But my hunch definitely goes in this direction."

If he's right, it would have meaning beyond proving an arrow of time exists outside of our consciousness. The link between clocks and thermodynamics may also reflect time on a smaller scale. If there is a limit on how accurately we can resolve time, could this be a sign that time itself isn't perfectly smooth, but instead lumpy – packed into tiny units in the same way that light comes in photons?

Answering this could be tricky. To probe space-time at this tiniest of scales, below those we can currently reach with our best particle accelerators, would require vast amounts of energy. At a certain level of energy, you would expect to create a black hole that would swallow the entire experiment, suggesting it is impossible to resolve time perfectly. "You end up with a sort of fundamental limit on the sensitivity to which you can measure a time interval," says Adlam. This might be related to the limit caused by thermodynamics, she says, but the link isn't clear yet.

Probing time at minuscule scales is exciting, but what Huber is most thrilled about relates to quantum mechanics and a mystery called the measurement problem. "I have a long-standing obsession with it," he says.

> "Could this be a sign that time is not perfectly smooth, but lumpy – packed into tiny units?"

Unlike relativity, in which time is local and relative, quantum mechanics assumes there is a universal background time. Time in quantum mechanics doesn't have an arrow: equations work equally well forwards as backwards in time. But sometimes this reversibility can be broken. When we measure a quantum system, the act of measuring causes the system to collapse from a superposition, a mix of different possible states, into a specific outcome. This cannot be reversed, creating an arrow of time. How time manages both to have, and not have, an arrow is just one of quantum mechanics' many puzzles. But if the thermodynamic arrow can explain our perceptual time arrow, maybe it can explain the quantum one too.

This is what Huber wants to tackle next. We know that whenever we measure something, we affect it, but the nitty-gritty of this process is often ignored in quantum mechanics. According to Huber, the act of measuring should create a flow of energy that may be best described by the laws of thermodynamics. "I think the measurement postulate is the second law in disguise," he says. Perhaps quantum measurements, like clocks, create rising entropy and hence an emergent arrow of time.

Erker, on the other hand, points out the research could also help to test ideas that combine the notoriously clashing theories of quantum mechanics and general relativity into a quantum theory of gravity. Such tests are extremely hard. Because gravity is so weak, you either need to put massive objects in a quantum superposition state to probe gravitational effects,which is tricky and has only been done in molecules of up to 2000 atoms. Or you need to be able to make incredibly precise measurements – and quantum clocks could help with that. "If we could build clocks that are accurate on very short timescales, we could actually build tabletop quantum experiments that test for gravitational effects," says Erker.

Any theory that explains gravity and quantum mechanics needs to describe how clocks work on the quantum scale. "All this research on understanding what clocks really are and how they kind of interact with quantum mechanics and with relativity is probably an important step to understanding how those theories fit together," says Adlam.

Bergson and Einstein's debate cost the physicist the Nobel prize for general relativity. The president of the Nobel committee said that, while it was complex, "it will be no secret that the famous philosopher Bergson in Paris has challenged this theory". Instead, Einstein won for the less-glamorous photoelectric effect. But a century on, Einstein now seems the real winner of the debate. The next question is whether there will ever be a way to merge his theory of general relativity with quantum mechanics. On that, only time will tell. ▮

Miriam Frankel is a science journalist based in London

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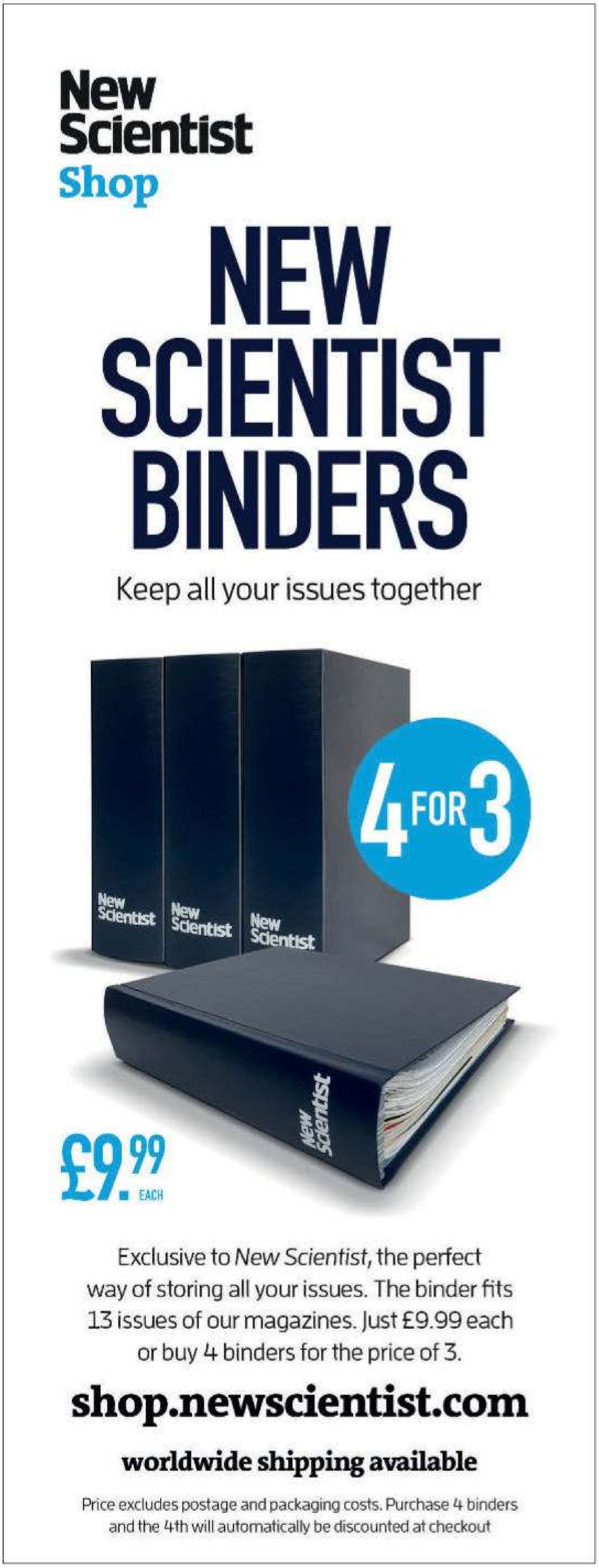
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Stargazing at home

Triangulating Triangulum

The new year is the perfect chance to see the most distant galaxy visible to the naked eye, says **Abigail Beall**

Abigail Beall is a feature editor at *New Scientist* and author of *The Art of Urban Astronomy* @abbybeall

What you need

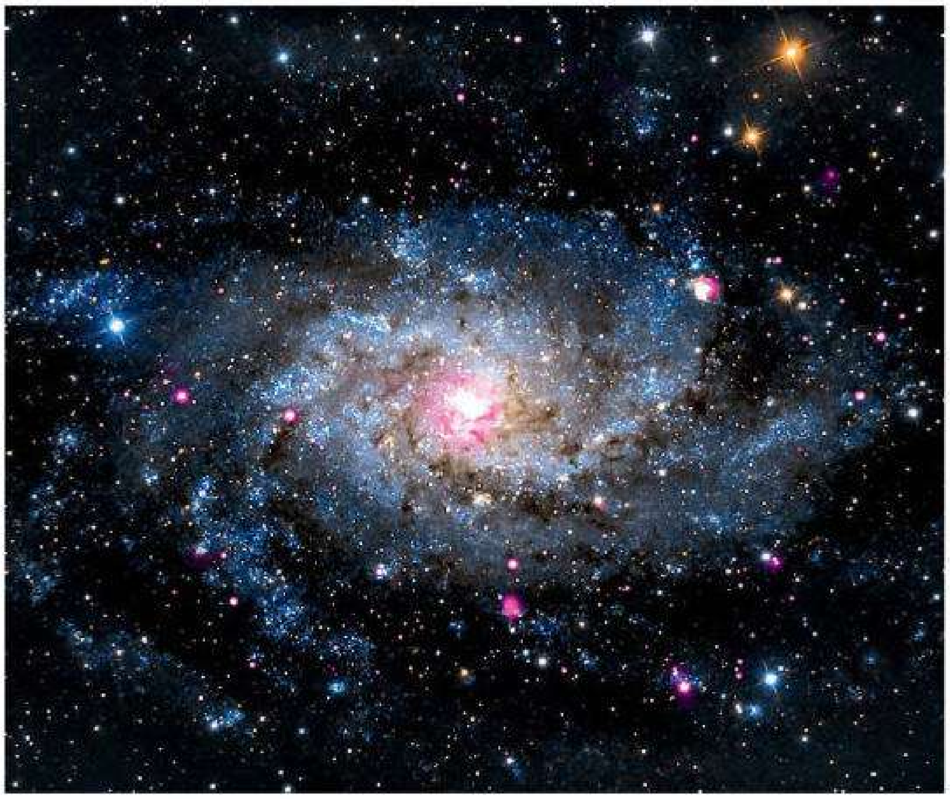
A very dark sky
Binoculars

THE first week of the new year brings us a new moon, and the perfect time to hunt for the fainter objects in the night sky. I will be looking to spot a galaxy called Triangulum, or M33, which can be seen from anywhere in the world with dark skies this time of year.

The most famous galaxy that can be viewed from Earth with the naked eye is Andromeda, our neighbouring one, which is 2.5 million light years away. We have previously looked at how to spot the Andromeda galaxy (14 December 2019), and this is often cited as the most distant object from us that is visible with the naked eye. But M33 is even further away and can sometimes be seen with no assistance, although you need to be in a place with exceptionally dark skies.

Triangulum is a spiral galaxy 2.7 million light years from Earth. It is the third-largest member of the local group of galaxies, after Andromeda and our own, the Milky Way. It was first catalogued by Charles Messier in 1764, when it was named Messier 33, though it may well have been spotted by someone else before this.

It was thought to be a nebula – a huge cloud of gas and dust – in our own galaxy. But in the 1920s, Edwin Hubble showed that some variable stars in Triangulum had characteristics that enabled him to estimate their distance. From this, he demonstrated that Triangulum was a galaxy in its own right.



NASA/CXC/SAO/P. PLUCINSKY ET AL.

It is so faint because it boasts only about 40 million stars, compared with the trillion or so in Andromeda. As a result, Triangulum can only be seen with the naked eye from places with excellent viewing conditions. If you don't have access to a dark sky reserve, you can try looking with binoculars. Either way, get away from any sources of light and let your eyes adjust for as long as possible before looking for it.

Triangulum sits near the Andromeda galaxy in the night sky. First, find the constellation of Triangulum, a small one between the Andromeda constellation and Taurus, which we have previously found (2 November 2019). To do this, draw a line between the bright star Aldebaran in Taurus and the small bright cluster of stars, the Pleiades, also in Taurus, and continue this in the direction of Andromeda until you see three stars forming a small triangle. These are Gamma Trianguli and Beta Trianguli, close to each other, with Mothallah making up the third point of the triangle.

Next, find the Triangulum galaxy. To locate it, look between Mothallah and Mirach, the bright star in the centre of the constellation Andromeda. The galaxy sits about a third of the way from Mothallah to Mirach. It should look like a fuzzy blob, roughly the shape of an egg.

Remember, you will need extremely dark skies to see it, and it is tricky to find, so don't worry if you don't pick it out immediately. Good luck! ▮

Stargazing at home appears every four weeks

Next week

Science of gardening

These articles are posted each week at newscientist.com/maker

New Scientist Jobs

2022
GLOBAL SCIENCE
EMPLOYMENT SURVEY

New Scientist Jobs, in association with SRG, is conducting its 2022 Global Science Employment survey to provide you with the latest insights into your industry. We will benchmark salary data, as well as topical issues such as employee satisfaction, your employer's response to covid-19 and discrimination in the workplace. We would love your thoughts and feedback on these topics and more to help us create the 2022 Global Science Employment report.

The survey takes less than 10 minutes to complete and, as a thank you, all respondents who complete the survey will have the option to be entered into a prize draw to win one of five £100 (or local equivalent) Amazon eGift cards and receive a pdf copy of the 2022 Global Science Employment Report when it is published.

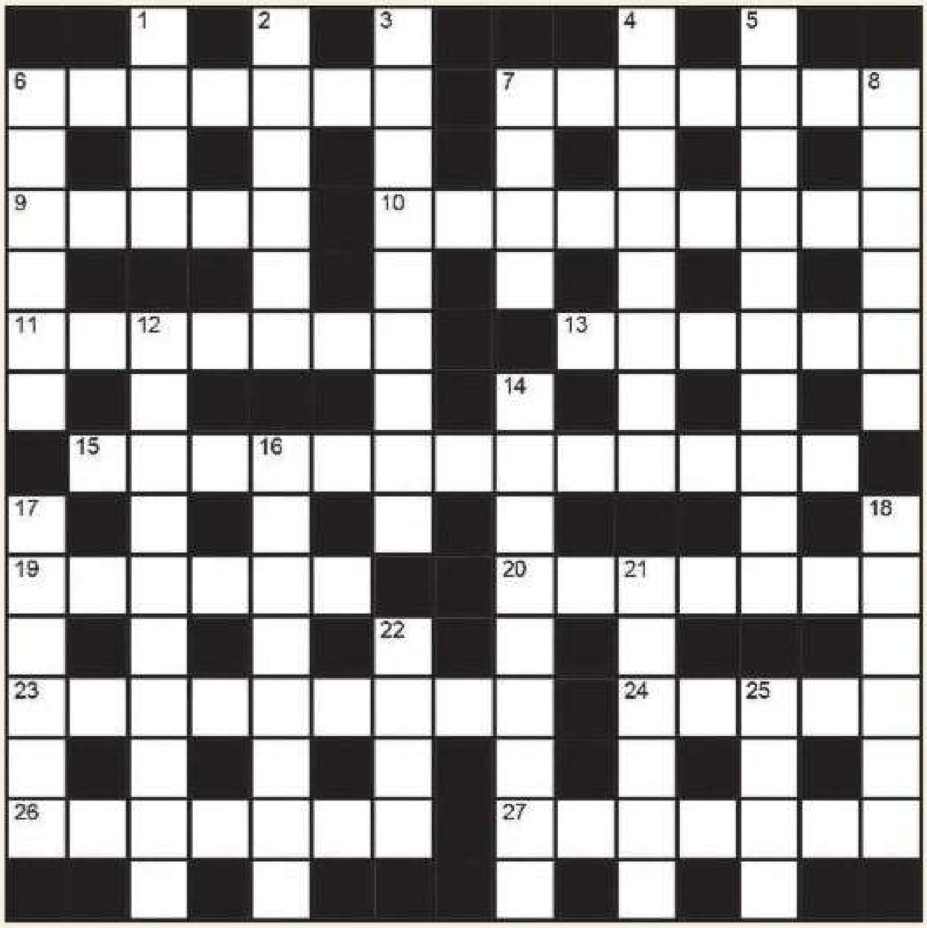
To find out more and complete the survey, go to

newscientist.com/globalemploymentsurvey

IN ASSOCIATION WITH srg

The winners of the prize draw will be notified on 24/01/2022.

Quick crossword #98 *Set by Richard Smyth*



Scribble zone

Answers and the next cryptic crossword next week

ACROSS

6 Instrument for measuring current (7)
7 See 6 Down
9 Smaller in number (5)
10 kV (9)
11 ε (7)
13 Naturally formed narrow waterway (6)
15 Author of *The Formation of Vegetable Mould through the Action of Worms* (1881) (7,6)
19 Transmit from one computer system to another (6)
20 ___ reactor, atomic pile (7)
23 Element with chemical symbol Sr (9)
24 Extent (5)
26 Aquatic plants in the genus *Nelumbo* (7)
27 Growth of crystals on a crystalline substrate (7)

DOWN

1 Sea duck *Mergellus albellus* (4)
2 Organic compound, $C_{17}H_{28}O$ (6)
3 Fractured femur, perhaps (6,3)
4 Lift (8)
5 Intended to relieve or mitigate symptoms (10)
6/17/7Across Author of *Contributions to the Theory of Natural Selection* (1870) (6, 6, 7)
7 Fuse together by melting and cooling (4)
8 Substitute; (inferior) imitation (6)
12 Sulphide mineral: (Zn, Fe)S (10)
14 Three, five or seven, perhaps (3,6)
16 Actuality (8)
17 See 6
18 Major blood vessel (6)
21 Lower part of the uterus (6)
22 Spectrum of conditions caused by HIV (4)
25 In close proximity to (4)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #132

1 In meteorology, an area of high pressure that stays relatively still over a region is known as a what?

2 Vargulin and coelenterazine are examples of which class of light-emitting compound found in bioluminescent organisms?

3 Where would you find Kamo'oalewa?

4 Which highly reactive element has the atomic number 17?

5 What name is given to a juvenile newt?

Answers on page 55

Puzzle

set by Katie Steckles

#148 Much ado about muffins

Nine local bakers were challenged to produce enough muffins for everyone in the village. And they did it! Each baker brought the same number of muffins, and overall there were an equal number of muffins in each of eight different flavours. But the two tables set out to display them were too small.

"Could we get a third table and share them evenly between three tables?" asked Eccles.

"Yes, we could!" said Victoria. But after wheeling in a third table, the tables looked too crowded. A fourth, fifth, sixth and – finally – seventh table was wheeled in, and impressively, after each table was added, the original pile of muffins could still be equally divided between the tables.

"Well, shuffle my muffins!" exclaimed the mathematically astute Madeleine. "We made the smallest total of muffins we could have made for which this series of events could have played out!"

How many muffins did the bakers produce in total?

Solution next week

Why five?

Why do we and many other animals have five digits on each hand and foot? Why not some other number?

Natalie Roberts
Watford, Hertfordshire, UK
Several years ago, I watched a documentary about the fossil of an early amphibian, once encased in a stone nodule. When it was discovered, in Victorian times, five toes were uncovered on each foot, then the excavation stopped. However, some stone was still left around the feet.

A couple of years before the documentary was recorded, curiosity led to further excavation. This was rewarded by the discovery of extra toes. There were in fact eight on each foot.

As well as a salutary lesson on not letting expectations prevent the completion of your research, this early amphibian proved that not all early land dwellers conformed to the five-digit rule. There was initial evolutionary experimentation; but only the five-toed amphibians were successful enough to pass on their genes.

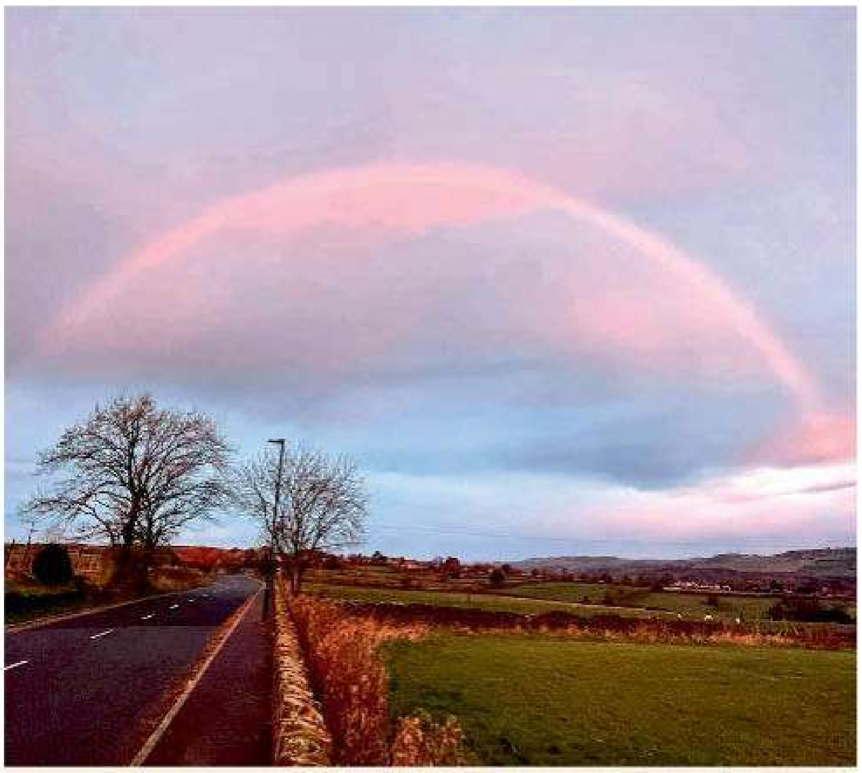
> “The first primitive digits appeared in fish-like animals and had a variety of digit numbers, often more than five”

Richard Swifte
Darmstadt, Germany
Limbs evolved from fish fins, and the first primitive digits appeared in fish-like, four-limbed animals in the Devonian period, 420 to 360 million years ago. These creatures were the ancestors of amphibians and ultimately reptiles, birds and mammals, and they exhibited variety in the number of digits, often having more than five.

The fossil record suggests that as these digits evolved accompanying bones and joints allowing more sophisticated use, their number reduced to no more than five. Subsequent evolution never increased this number.

In fact, many later animals have reduced the number still further when five weren’t needed. For example, the dinosaur branch known as theropods ended up with three fingers on each arm, or even two in the case of tyrannosaurs, while their probable descendants the birds mostly have four toes, and some just three or even two in the case of the ostrich.

Horses’ hooves are the result of just one toe developing to support the animals’ weight while galloping, with the other toes withering away. In humans and our ape relatives, one finger evolved into the opposing thumb, which allowed us to better grasp things.



JODIE CALVERT

Why is this rainbow just red rather than having the typical spectrum of seven colours?

This week’s new questions

Red rainbow **My friend spotted a strange red-only “rainbow” (pictured) just after sunrise. There was no rain, so what caused this?** ***Phil Eden****, Sheffield, UK*

Young and loud **Babies and children make a lot of noise when they cry and shriek. Why do the young of other animals seem generally much quieter?** ***Greg Lawrence****, Canberra, Australia*

Factual evolution

When does a theory become a fact and who decides?

Wolf Kirchmeir
Blind River, Ontario, Canada
A theory never becomes a fact. It is an explanation of one or more facts.

Tim Lewis
Narberth, Pembrokeshire, UK
A well-supported evidence-based theory becomes acceptable until disproved. It never evolves to a fact, and that’s a fact.

Nick Canning
Coleraine, County Londonderry, UK
Many scientists, including the late Stephen Hawking, are happy to say that a theory never becomes a fact. It is always an interpretive structure that links facts, which are themselves reproducible experimental observations.

The “truth” of a theory is determined by its usefulness in linking the largest number of facts and predicting new ones that haven’t been observed yet. Discovery of facts that don’t fit the theory will lead to the search for a new theory.

Matt Chamings
Barnstaple, Devon, UK
This question misunderstands what a theory is in the same way that creationists dismiss evolution as “just a theory”.

A theory isn’t speculation about what might be true. It is a set of propositions that seek to explain a particular phenomenon or set of facts. A theory can be tested and shown to be accurate or modified as the evidence requires. Even when a theory is accepted as fact, it remains a theory.

Alan Harding
London, UK
While a scientific theory such as Isaac Newton’s theory of gravitation makes an infinite number of predictions, it can only be verified by a finite number of observations, so it can never be seen as irrefutably correct. In philosophy, this is the problem of induction.

The fact that science rests on rather fragile epistemological foundations opens it to attack from anti-science movements, for example when creationists claim that Darwinian evolution is “only a theory”. All science is, to some extent, “only a theory”, but its great strength is that theories that don’t fit real world observations are eventually discarded. This has happened with Newton’s theory of gravitation, now seen to be a special case of general relativity.

So in reality, in science we do not have facts or proof, all we have

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Tom Gauld
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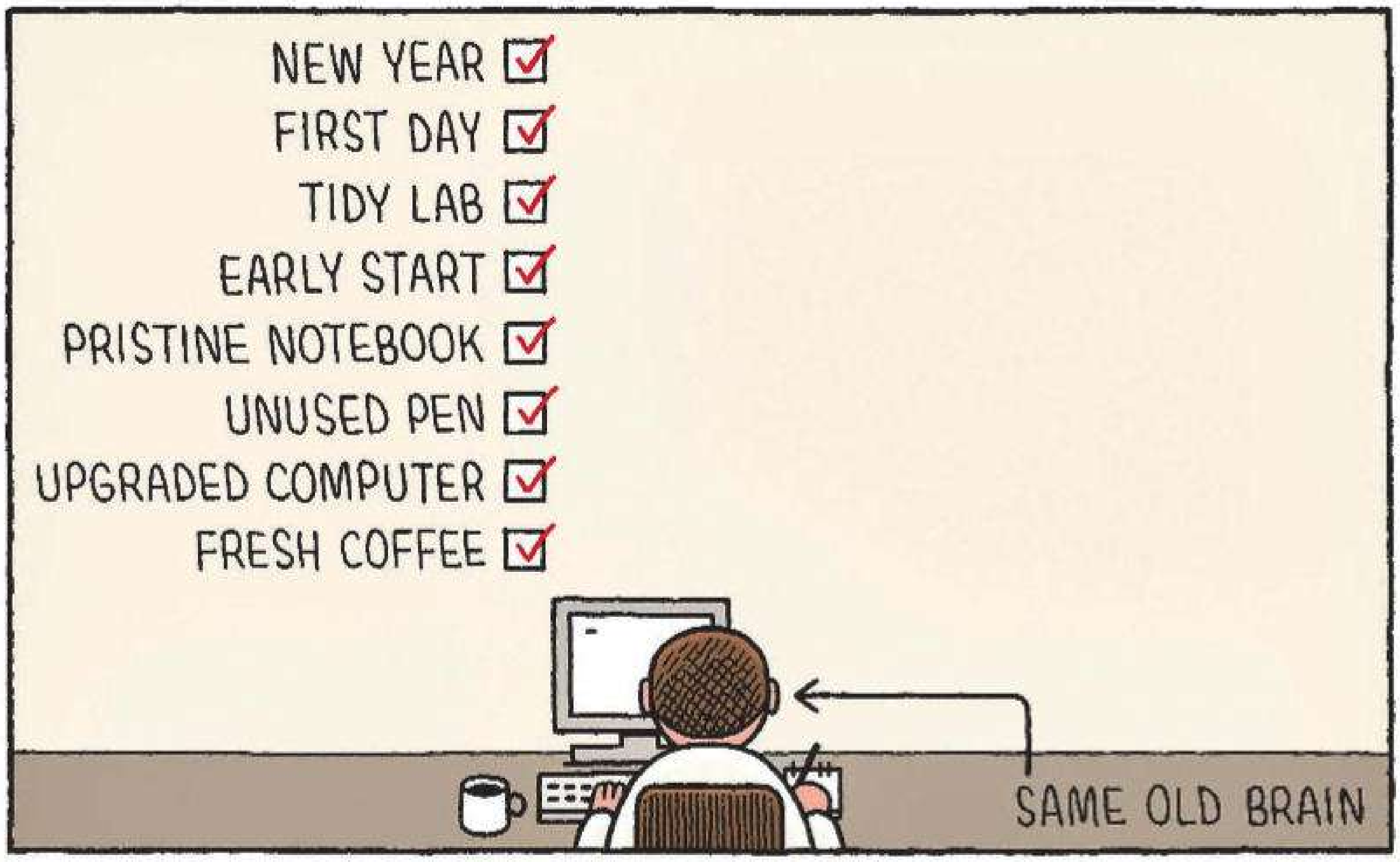


is the best-available, most widely accepted theory at the time.

John Wallace
Liverpool, UK
Evolutionary pressures have favoured some organisms that are aware of their surroundings and able to react to them. Humans have become rather good at this.

We also have curiosity, which leads us to look hard at our surroundings and try to make sense of what we find. So, we gather information, and try to invent theories that could explain what we see. The better theories don't just explain all the data so far observed, they enable predictions. If confirmed by data, this strengthens our reliance on the theory.

Take satnav systems, for example. These rely on the predictions of relativity and quantum theories. Every time a satnav system is used, the theories it was based on are tested again. But, until we know "everything", theories, even the successful ones, will still be theories.

> **"An evidence-based theory becomes acceptable until disproved. It never evolves to a fact, and that's a fact"**

Raining bullets

I cringe when I see soldiers celebrating by shooting their rifles into the air. What speed do the bullets return to the ground and could they hurt someone? (continued)

Anthony Battersby
Bath, UK
In the 1970s, I worked in Beirut in Lebanon. My boss was walking down Rue Hamra, the main street in West Beirut, with his wife when he suddenly collapsed. He had been struck by a falling bullet. It entered his body between his neck and collarbone and exited just above his kidneys.

He was incredibly lucky. The bullet was tumbling and so made a large entry wound and a larger exit wound, but it didn't hit any vital organs on the way through.

It had almost certainly been fired from some celebration up in the mountains behind the city.

James Davenport
Bath, UK
A friend of mine was hit on the head by a branch severed from a tree by bullets fired upwards at a celebration in Crete.

Fortunately, the branch was relatively small, and the consequences were just shock and a headache.

Glenn Pickard
Baldwin Park, California, US
From 1974 to 2006, I worked in commercial roofing in California. I picked up or extracted more than 900 bullets from the roofs of warehouses, factories and residential building that I inspected.

These bullets were presumably the result of guns being fired into the air, but the damage to the roofs was usually minimal.

Answers

Quick quiz #132
Answers

1 A block, blocking anticyclone or blocking high

2 Luciferins

3 In space. An asteroid about 40 metres in diameter, it is a quasi-satellite of Earth

4 Chlorine

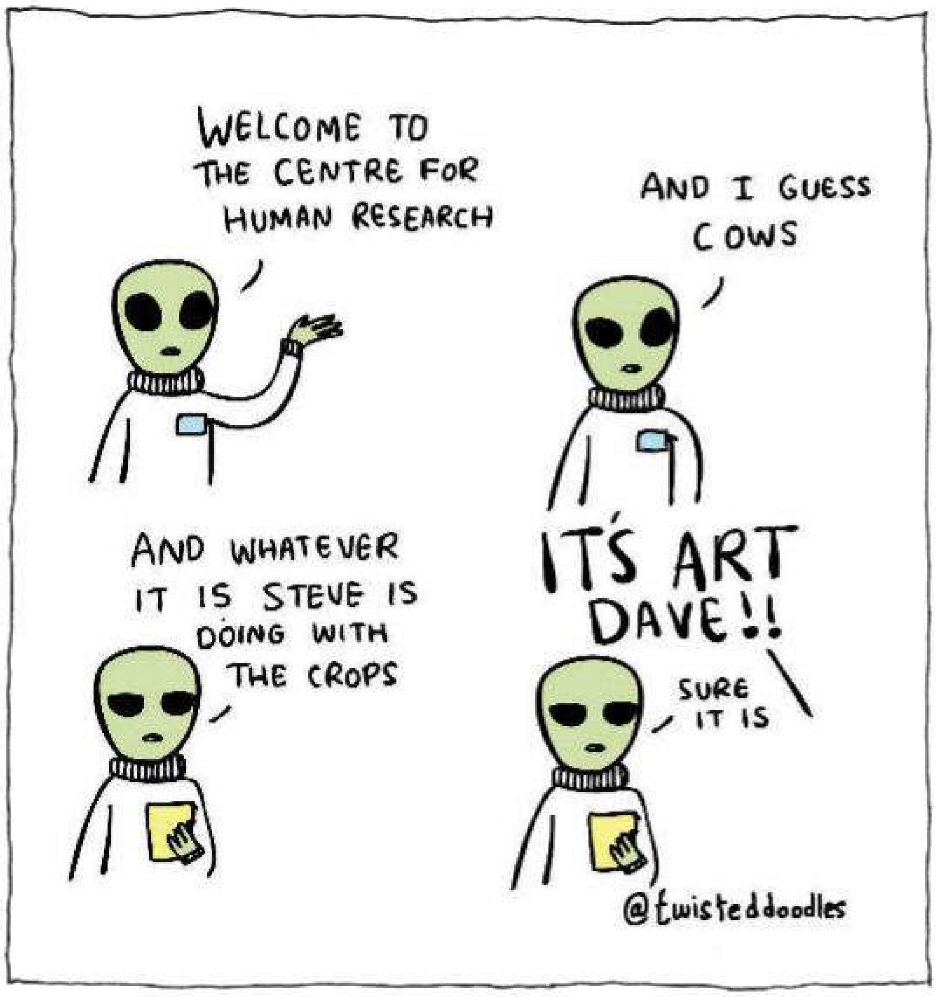
5 An eft

Cryptic crossword #73 *Answers*

ACROSS 1 Ejector seat, **7** Jetpack, **11** Dismember, **12** Simpleton, **13** Swaddle, **14** Drupe, **15** Yanks, **16** Elect, **18** Time, **20** Autogiro, **23** Methane, **25** Roam, **26** Pledge, **29** Geiger, **30** Rift, **31** Mislead, **34** Ladybird, **36** Anal, **37** Rebel, **40** Extra, **42** Gleam, **44** Fleming, **46** Exoplanet, **47** Guidepost, **48** Entreat, **49** X-ray glasses

DOWN 1 Endosperm, **2** Ensnare, **3** Trend, **4** Rebreather, **5** Erred, **6** Tissue, **7** Jumped-up, **8** Tally-ho, **9/19** Aston Martin, **10** Kinescope, **17** Trace, **21** Indie, **22** Dalton, **24** Triad, **27** Laser, **28** Amplifying, **29** Goldeneye, **32** Delegates, **33** Dragonet, **35** Braille, **38** Britons, **39** Semtex, **41** Trout, **43** Magma, **45** Enema

Twisteddoodles *for New Scientist*


WELCOME TO THE CENTRE FOR HUMAN RESEARCH
AND I GUESS COWS
AND WHATEVER IT IS STEVE IS DOING WITH THE CROPS
IT'S ART DAVE!!
SURE IT IS
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Send it to feedback@newscientist.com or New Scientist, Northcliffe House, 2 Derry Street, London W8 5TT
Consideration of items sent in the post will be delayed

Glowing reports

Happy new year, happy new year – may we all have a vision, now and then, of a world where every neighbour is a friend! You catch us having our annual bath, singing along to ABBA's traditional Swedish seasonal carol and possibly still feeling the effects of one too many Tío Pepes. Well, what do you expect in a column dated 1 January?

We are put in a particularly good mood, however, by Tony Powers, who writes with a follow-up to an article last year about platypuses, those remarkable mammals that glow in UV light, produce venom and lay eggs (8 May 2021, p 41). Tony's "sciencechildren" – like godchildren, only evidence-based – Sarah and Rebecca, aged 10 and 8, used a visit to the Australian Museum in Sydney to test animals for fluorescence using a UV hand torch. Their results in near-full:

Platypus – do indeed glow green. Some specimens also have glowing white patches under the eyes;

Long-beaked and short-beaked echidnas – quills and short hairs glow different colours;

Mountain pygmy possum and rabbit-eared bandicoot (or bilby) – exposed skin and ear hair glows white;

Koala – white fur patches glow;

Wombat – nose glows blue;

Masked owl – white feathers under eyes glow;

Peregrine falcon – leg skin green.

"They were unable to check if the fluorescence was an artefact of taxidermy," Tony adds. "That will await a trip to the zoo."

Never grows old...

Also faintly glowing, Guy Cox from Sydney in Australia joins a tidal wave of mainly self-professed older readers writing in defence of illuminated toilet bowls (27 November 2021). Guy also adds to our musings on how old the internet and other authorities assume we can be (30 October 2021) with a story from his days at the University of Oxford. "A friend of mine found that, as an ecology postgrad, he was expected to take over as Secretary of the Ashmolean Natural History Society," he writes. "His first action was to remove from the mailing list everyone who had been on it for more than 100 years."

Out of this world comms

"Dear BackPages Feedback," Rita Hardman from the Melbourne Dental School writes, startling us: we had thought that, like Rumpelstiltskin or Prince Calaf from the opera *Turandot*, our given name was a thing of mystery.

Rita also has a mailing list story, reporting that she received, on 16 November 2021, a *New Scientist* subscription renewal reminder dated 18 May 2021, embellished with a FUN! fact: "The world's fastest spacecraft took 12 weeks to reach the sun". "I think it's safe to say that the world's fastest postal service was not in charge of delivering my letter," she says.

She further goes on to calculate, in the admirable way of many dear readers, that were the letter sent at that speed from London not to Melbourne, but to the sun, she would have received it roughly 4407 years later – missing out on a goodly few issues.

Our apologies on behalf of the postal services of the world and beyond. Memo to the marketing team: if the solar system subs drive isn't going so well, it is because the magazine is only 65 years old and they may not have heard of us yet.

For Auld Lang Syne

An objection with late fervour and a loudhailer from Melbourne to the account of our escape from the stationery cupboard to the COP26 climate summit in Glasgow (20 November 2021).

Nigel Sinnott takes issue with our reference to the city as "the Gaelic 'dear green place'". "Although the Gaelic name of the place is Glaschu, I think you will find that the name was originally Old British, the parent language of Welsh and Cornish," he writes. "The word *glas* (green, greenish-grey and related colours) is common to both Brythonic and Goidelic languages, but *cu* is probably from an Old British term for "hollow" or "ravine" (Modern Welsh *cau*)." Now how's that for international cultural enrichment.

How many fish in a bird?

We admit we are glad not to have been woken up today of all days by "New Zealand's most annoying tūī", the subject of a story on stuff.co.nz spotted by Martin Hucklesby from Nelson. "Every spring, New Zealand's song birds from hell traumatise the suburbs with their raucous cacophonies. While they're supposed to get quieter from about October, my tūī obviously didn't get the memo," writes Virginia Fallon.

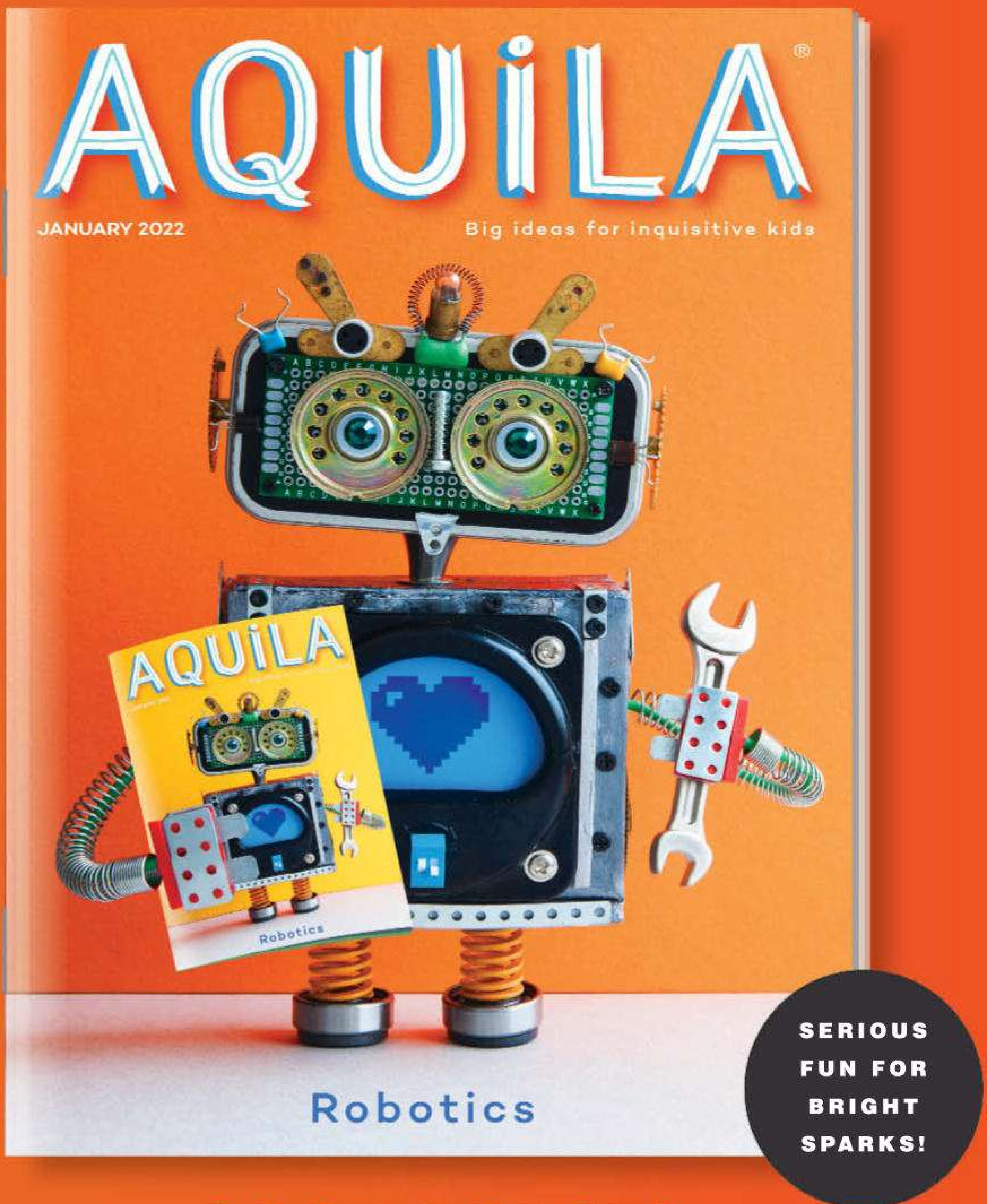
Feedback has some unruly sparrows in our eaves – and no, that's not a euphemism – but we have as yet nothing capable of mimicking a car alarm or giving out "an extremely loud *honk*, something in between an airhorn and a startled mega-goose".

Martin is mainly keen, however, that we take note that the tūī is "a bird weighing just 125 grams – the equivalent of five chocolate fish". To anyone still in the new year fog, he points out that a chocolate fish is also not a euphemism, but a famed Kiwi sweetmeat.

Duly added to the pile of culturally relevant standard units, Martin. And since you introduce yourself as "a long time subscriber who *always* reads NS from back to front", may we end this column of delightful titbits from the other side of the globe by saying what a joy our world is, where not just our neighbours are our friends. Happy new year, wherever you are.

"...Advanced & Philosophical, Curious & Puzzling"

Richard Robinson, Brighton Science Festival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